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**UTILITY
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First Inventor or Application Identifier William A. Fuglevand

Title Fuel Cell Power Systems and Methods of
Controlling a Fuel Cell Power System

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APPLICATION ELEMENTS
See MPEP chapter 600 concerning utility patent application contents.ADDRESS TO: Assistant Commissioner for Patents
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1. ☒ * Fee Transmittal Form (e.g., PTO/SB/17)
(Submit an original and a duplicate for fee processing)
2. ☒ Specification [Total Pages 104]
(preferred arrangement set forth below)
- Descriptive title of the Invention
 - Cross References to Related Applications
 - Statement Regarding Fed sponsored R & D
 - Reference to Microfiche Appendix
 - Background of the Invention
 - Brief Summary of the Invention
 - Brief Description of the Drawings (if filed)
 - Detailed Description
 - Claim(s)
 - Abstract of the Disclosure
3. ☒ Drawing(s) (35 U.S.C. 113) [Total Sheets 28]
4. Oath or Declaration [Total Pages 4]
- a. ☒ Newly executed (original or copy)
- b. ☐ Copy from a prior application (37 C.F.R. § 1.63(d))
(for continuation/divisional with Box 16 completed)
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Signed statement attached deleting
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5. ☐ Microfiche Computer Program (Appendix)
6. Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)
- a. ☐ Computer Readable Copy
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ACCOMPANYING APPLICATION PARTS

7. ☒ Assignment Papers (cover sheet & document(s))
8. ☐ 37 C.F.R. § 3.73(b) Statement of Power of Attorney
(when there is an assignee)
9. ☐ English Translation Document (if applicable)
10. ☐ Information Disclosure Statement (IDS)/PTO-1449 [Copies of IDS Citations]
11. ☐ Preliminary Amendment
12. ☒ Return Receipt Postcard (MPEP 503)
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APPLICATION FOR LETTERS PATENT

* * * * *

FUEL CELL POWER SYSTEMS AND METHODS OF
CONTROLLING A FUEL CELL POWER SYSTEM

* * * * *

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ATTORNEY'S DOCKET NO. WA23-015

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1 **FUEL CELL POWER SYSTEMS AND METHODS OF**
2 **CONTROLLING A FUEL CELL POWER SYSTEM**

3 **RELATED PATENT DATA**

4 The present application is a continuation-in-part of U. S. Patent
5 Application Serial No. 09/108,667, filed on July 1, 1998, which was a
6 continuation-in-part of U.S. Patent Application Serial No. 08/979,853,
7 filed on November 20, 1997.

8
9 **TECHNICAL FIELD**

10 The present invention relates to fuel cell power systems and
11 methods of controlling a fuel cell power system.

12
13 **BACKGROUND OF THE INVENTION**

14 Fuel cells are known in the art. The fuel cell is an
15 electrochemical device which reacts hydrogen, and oxygen, which is
16 usually supplied from the ambient air, to produce electricity and water.
17 The basic process is highly efficient and fuel cells fueled directly by
18 hydrogen are substantially pollution free. Further, since fuel cells can
19 be assembled into stacks of various sizes, power systems have been
20 developed to produce a wide range of electrical power output levels and
21 thus can be employed in numerous industrial applications.

22 Although the fundamental electrochemical processes involved in all
23 fuel cells are well understood, engineering solutions have proved elusive
24 for making certain fuel cell types reliable, and for others economical.

1 In the case of polymer electrolyte membrane (PEM) fuel cell power
2 systems reliability has not been the driving concern to date, but rather
3 the installed cost per watt of generation capacity has. In order to
4 further lower the PEM fuel cell cost per watt, much attention has been
5 directed to increasing the power output of same. Historically, this has
6 resulted in additional sophisticated balance-of-plant systems which are
7 necessary to optimize and maintain high PEM fuel cell power output.
8 A consequence of highly complex balance-of-plant systems is that they
9 do not readily scale down to low capacity applications. Consequently,
10 cost, efficiency, reliability and maintenance expenses are all adversely
11 effected in low generation applications.

12 It is well known that single PEM fuel cells produce a useful
13 voltage of only about 0.45 to about 0.7 volts D.C. per cell under a
14 load. Practical PEM fuel cell plants have been built from multiple cells
15 stacked together such that they are electrically connected in series. It
16 is further well known that PEM fuel cells can operate at higher power
17 output levels when supplemental humidification is made available to the
18 proton exchange membrane (electrolyte). In this regard, humidification
19 lowers the resistance of proton exchange membranes to proton flow.
20 To achieve this increased humidification, supplemental water can be
21 introduced into the hydrogen or oxygen streams by various methods, or
22 more directly to the proton exchange membrane by means of the
23 physical phenomenon known as of wicking, for example. The focus of
24 investigations, however, in recent years has been to develop membrane

1 electrode assemblies (MEA) with increasingly improved power output
 2 when running without supplemental humidification. Being able to run
 3 an MEA when it is self-humidified is advantageous because it decreases
 4 the complexity of the balance-of-plant with its associated costs.
 5 However, self-humidification heretofore has resulted in fuel cells running
 6 at lower current densities and thus, in turn, has resulted in more of
 7 these assemblies being required in order to generate a given amount of
 8 power.

9 While PEM fuel cells of various designs have operated with
 10 varying degrees of success, they have also had shortcomings which have
 11 detracted from their usefulness. For example, PEM fuel cell power
 12 systems typically have a number of individual fuel cells which are
 13 serially electrically connected (stacked) together so that the power
 14 system can have a increased output voltage. In this arrangement, if
 15 one of the fuel cells in the stack fails, it no longer contributes voltage
 16 and power. One of the more common failures of such PEM fuel cell
 17 power systems is where a membrane electrode assembly (MEA) becomes
 18 less hydrated than other MEAs in the same fuel cell stack. This loss
 19 of membrane hydration increases the electrical resistance of the effected
 20 fuel cell, and thus results in more waste heat being generated. In turn,
 21 this additional heat dries out the membrane electrode assembly. This
 22 situation creates a negative hydration spiral. The continual overheating
 23 of the fuel cell can eventually cause the polarity of the effected fuel
 24 cell to reverse such that it now begins to dissipate electrical power

1 from the rest of the fuel cells in the stack. If this condition is not
2 rectified, excessive heat generated by the failing fuel cell may cause the
3 membrane electrode assembly to perforate and thereby leak hydrogen.
4 When this perforation occurs the fuel cell stack must be completely
5 disassembled and repaired. Depending upon the design of fuel cell
6 stack being employed, this repair or replacement may be a costly, and
7 time consuming endeavor.

8 Further, designers have long sought after a means by which
9 current densities in self-humidified PEM fuel cells can be enhanced
10 while simultaneously not increasing the balance-of-plant requirements for
11 these same devices.

12 13 **BRIEF DESCRIPTION OF THE DRAWINGS**

14 Preferred embodiments of the invention are described below with
15 reference to the following accompanying drawings.

16 Fig. 1 is a prospective view of one embodiment of a fuel cell
17 power system according to the present invention.

18 Fig. 2 is an illustrative representation of a control system coupled
19 with components of the fuel cell power system.

20 Fig. 3 is an exploded perspective view of one configuration of a
21 fuel cell cartridge of the fuel cell power system.

22 Fig. 4 is a schematic representation of one embodiment of
23 circuitry coupled with plural fuel cells of the fuel cell cartridge.
24

1 Fig. 5 is a functional block diagram of one configuration of the
2 control system for the fuel cell power system.

3 Fig. 6 is a functional block diagram of a cartridge analysis slave
4 controller of the control system coupled with associated circuitry and
5 components.

6 Fig. 7 is a functional block diagram of an auxiliary valve slave
7 controller of the control system coupled with associated circuitry and
8 components.

9 Fig. 8 is a functional block diagram of a fan slave controller of
10 the control system coupled with associated circuitry and components.

11 Fig. 9 is a functional block diagram of an interface slave
12 controller of the control system coupled with associated circuitry and
13 components.

14 Fig. 10 is a functional block diagram of an external port slave
15 controller of the control system coupled with associated circuitry and
16 components.

17 Fig. 11 is a functional block diagram of a system analysis slave
18 controller of the control system coupled with associated circuitry and
19 components.

20 Fig. 12 is a functional block diagram of a sensor slave controller
21 of the control system coupled with associated circuitry and components.

22 Fig. 13 is a functional block diagram of an air temperature slave
23 controller of the control system coupled with associated circuitry and
24 components.

Fig. 14 is a functional block diagram of a shunt slave controller of the control system coupled with associated circuitry and components.

Fig. 15 is a functional block diagram of a switch slave controller of the control system coupled with associated circuitry and components.

Figs. 16-16A are a flow chart illustrating exemplary operations of a master controller of the control system.

Fig. 17 is a flow chart illustrating an exemplary start-up operation of the master controller.

Figs. 18-18A are a flow chart illustrating exemplary error operations of the master controller.

Figs. 19-19B are a flow chart of exemplary operations of the cartridge analysis slave controller.

Figs. 20-20A are a flow chart illustrating exemplary operations of the auxiliary valve slave controller of the control system.

Figs. 21-21A are a flow chart illustrating exemplary operations of the fan slave controller of the control system.

Fig. 22 is a flow chart illustrating exemplary operations of the interface slave controller of the control system.

Fig. 23 is a flow chart illustrating exemplary operations of the external port slave controller of the control system.

Figs. 24-24A are a flow chart illustrating exemplary operations of the system analysis slave controller of the control system.

Fig. 25 is a flow chart illustrating exemplary operations of the sensor slave controller of the control system.

1 Fig. 26 is a flow chart illustrating exemplary operations of the air
2 temperature slave controller of the control system.

3 Fig. 27 is a flow chart illustrating exemplary operations of the
4 shunt slave controller of the control system.

5 Fig. 28 is a flow chart illustrating exemplary operations of the
6 switch slave controller of the control system.

7
8 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

9 This disclosure of the invention is submitted in furtherance of the
10 constitutional purposes of the U.S. Patent Laws "to promote the
11 progress of science and useful arts" (Article 1, Section 8).

12 Referring to Fig. 1, one configuration of a fuel cell power
13 system 10 is illustrated. The depicted configuration of fuel cell power
14 system 10 is exemplary and other configurations are possible. As
15 shown, fuel cell power system 10 includes a housing 12 provided about
16 a plurality of fuel cell cartridges 14. Housing 12 defines a subrack
17 assembly in the described embodiment.

18 Fuel cell power system 10 is configured to utilize one or more
19 of fuel cell cartridges 14. Twelve such fuel cell cartridges 14 are
20 utilized in the embodiment of fuel cell power 10 described herein. As
21 described below, individual fuel cell cartridges 14 include a plurality of
22 fuel cells. In the described configuration, individual fuel cell
23 cartridges 14 include four fuel cells.
24

Such fuel cells can comprise polymer electrolyte membrane (PEM) fuel cells. In the described embodiment, the fuel cells can comprise membrane electrode assembly (MEA) fuel cells or membrane electrode diffusion assembly (MEDA) fuel cells. Further details of one configuration of fuel cells and fuel cell cartridges 14 are described in a co-pending U.S. Patent Application Serial No. 08/979,853, entitled "A Proton Exchange Membrane Fuel Cell Power System", filed November 20, 1997, naming William A. Fuglevand, Dr. Shiblihanna I. Bayyuk, Ph.D., Greg A. Lloyd, Peter D. Devries, David R. Lott, John P. Scartozzi, Gregory M. Somers and Ronald G. Stokes as inventors, assigned to the assignee hereof, having attorney docket number WA23-002, and incorporated herein by reference.

Housing 12 additionally includes an operator interface 16. In the present embodiment, operator interface 16 includes a display 18 and interface switches 20. Operator interface 16 is configured to indicate operation of fuel cell power system 10 and also enable an operator to control various functions of fuel cell power system 10.

Display 18 of operator interface 16 is configured to emit a human perceptible signal, such as visible signals, to indicate operation of fuel cell power system 10. In the depicted embodiment, display 18 comprises a plurality of light emitting diode (LED) bar graph arrays to indicate operational conditions of respective fuel cell cartridges 14. In one configuration, individual bar graph arrays of display 18 indicate high

1 and low voltages of fuel cells within the corresponding fuel cell
2 cartridge 14.

3 Interface switches 20 permit a user to control operations of fuel
4 cell power system 10. For example, one interface switch 20 can be
5 provided to enable a user to turn on fuel cell power system 10. In
6 addition, another interface switch 20 can include a load enable switch
7 which permits a user to selectively apply power from fuel cell power
8 system 10 to a load 22 coupled with the fuel cell power system 10.
9 Another interface switch 20 can control a cartridge reset function
10 described below.

11 Referring to Fig. 2, some components of fuel cell power
12 system 10 are shown. The components are internal and external of
13 housing 12 of fuel cell power system 10. Internally, only three fuel cell
14 cartridges 14 are shown for purposes of discussion herein. More fuel
15 cell cartridges 14 are provided in typical configurations.

16 Fuel cell power system 10 is shown coupled with a remote
17 device 24. Fuel cell power system 10 is preferably configured to
18 communicate with remote device 24. An exemplary remote device 24
19 comprises an off-site control and monitoring station. Fuel cell power
20 system 10 receives communications from remote device 24 which may
21 comprise data and commands. Fuel cell power system 10 is also
22 configured to output data, requests, etc. to remote device 24.

23 The depicted components include the plural fuel cell cartridges 14
24 and operator interface 16 discussed above. In addition, fuel cell power

1 system 10 includes a control system 30. One configuration of control
2 system 30 is described below in detail. The illustrated control
3 system 30 is coupled with a power supply sensor 31 associated with a
4 power supply 32, and charge circuitry 34. Control system 30 is
5 additionally coupled with fuel cell cartridges 14 and operator
6 interface 16. Further, control system 30 is coupled with a
7 communication port 36, switching device 38 and current sensor 40.
8 Control system 30 is additionally coupled with a bleed solenoid 42
9 associated with a bleed valve 43.

10 The depicted fuel cell power system 10 includes a fuel delivery
11 system 28. Fuel delivery system 28 couples with a fuel supply 23 to
12 supply fuel to fuel cell cartridges 14. Exemplary fuel comprises
13 hydrogen gas in the described embodiment. Other fuels may be
14 possible.

15 The depicted fuel delivery system 28 includes a main valve 47 and
16 plural auxiliary valves 45 associated with respective fuel cell
17 cartridges 14. Main valve 47 controls the flow of fuel from fuel
18 supply 23 into fuel cell power system 10. Auxiliary valves 45 control
19 the flow of fuel to respective fuel cell cartridges 14. Control system 30
20 is coupled with plural auxiliary solenoids 44 of associated auxiliary
21 valves 45. Control system 30 is further coupled with a main
22 solenoid 46 of associated main valve 47.

23 The depicted fuel cell power system 10 includes an air
24 temperature control assembly 50. The illustrated air temperature control

assembly 50 includes a plenum 51 having associated ports 52 corresponding to fuel cell cartridges 14. Within plenum 51 of air temperature control assembly 50, a temperature modifying element 53, fan 54, temperature sensor 55 and fuel sensor 61 are provided.

A controllable air flow device or air passage 56 couples plenum 51 to exterior ambient air outside of housing 12. Air passage 56 can permit the intake of air into plenum 51 as well as the exhaustion of air from plenum 51. Control system 30 is coupled with control circuitry 51 of modifying element 53, control circuitry 48 and monitoring circuitry 49 of fan 54, temperature circuitry 68 associated with temperature sensor 55, control circuitry 57 of air passage 56, and heater 75 of fuel sensor 61.

A first fuel sensor 58 is provided within housing 12 and outside of plenum 51 as shown. First fuel sensor 58 is operable to monitor for the presence of fuel within housing 12. A second fuel sensor 61 is provided within plenum 51 to monitor for the presence of fuel within plenum 51. Control system 30 is configured to couple with fuel detection circuitry 64 associated with fuel sensors 58, 61. Fuel detection circuitry 64 can condition measurements obtained from sensors 58, 61.

Heaters 74, 75 are coupled with respective fuel sensors 58, 61 to provide selective heating of fuel sensors 58, 61 responsive to control from control system 30. Heaters 74, 75 are integral of fuel sensors 58, 61 in some configurations. An exemplary fuel sensor

1 configuration with an integral heater has designation TGS 813 available
2 from Figaro Engineering, Inc. Such heaters are preferably provided in
3 a predefined temperature range to assure proper operation. Other
4 configurations of sensors 58, 61 are possible.

5 An external temperature sensor 59 is provided outside of
6 housing 12 in one embodiment. Control system 30 is also coupled with
7 temperature circuitry 67 associated with temperature sensor 59 to
8 monitor the exterior temperature. Temperature circuitry 67 conditions
9 signals received from temperature sensor 59.

10 Control system 30 is configured to at least one of control and
11 monitor at least one operation of fuel cell power system 10. During
12 operation, fuel from fuel supply 23 is applied to main valve 47. Main
13 valve 47 is coupled with auxiliary valves 45 as shown. Responsive to
14 control from control system 30, main valve 47 and auxiliary valves 45
15 apply fuel to respective fuel cell cartridges 14. Responsive to the
16 supply of fuel, and in the presence of oxygen, fuel cell cartridges 14
17 produce electrical power.

18 A power bus 60 couples the fuel cell cartridges 14 in series.
19 Power bus 60 is coupled with external terminals 62, 63 which may be
20 connected with an external load 22 (shown in Fig. 1). Terminal 62
21 provides a positive terminal and terminal 63 provides a negative
22 terminal of fuel cell power system 10.

23 Air temperature control assembly 50 applies oxygen to the
24 respective fuel cell cartridges 14 via ports 52. Fuel cell cartridges 14

are individually operable to convert chemical energy into electricity. As described below, fuel cartridges 14 individually contain plural fuel cells individually having an anode side and a cathode side. Auxiliary valves 45 apply fuel to the anode sides of the fuel cells. Plenum 51 directs air within the cathode sides of the fuel cells.

Air temperature control assembly 50 preferably provides circulated air within a predetermined temperature range. Such circulated air can be exterior air and/or recirculated air. In the preferred embodiment, air temperature control assembly 50 provides air within plenum 51 within an approximate temperature range of 25 °Celsius to 80 °Celsius.

Upon start-up conditions of fuel cell power system 10, modifying element 53 may be controlled via control system 30 using element control circuitry 41 to either increase or decrease the temperature of air present within plenum 51. Fan 54 operates to circulate the air within plenum 51 to respective fuel cell cartridges 14. Fan control circuitry 48 and fan monitor circuitry 49 are shown coupled with fan 54. Responsive to control from control system 30, fan control circuitry 48 operates to control air flow rates (e.g., speed of rotation) of fan 54. Fan monitor circuitry 49 operates to monitor the actual air flow rates induced by fan 54 (e.g., circuitry 49 can comprise a tachometer for rotational fan configurations).

Control system 30 monitors the temperature of the air within plenum 51 using temperature sensor 55. During operation, heat is generated and emitted from fuel cell cartridges 14. Thus, it may be

1 necessary to decrease the temperature of air within plenum 51 to
2 provide efficient operation of fuel cell power system 10. Responsive to
3 control from control system 30, air passage 56 can be utilized to
4 introduce exterior air into plenum 51 and exhaust air from plenum 51
5 to ambient.

6 Control system 30 communicates with control circuitry 57 to
7 control air passage 56. In one embodiment, air passage 56 includes a
8 plurality of vanes and control circuitry 57 operates to control the
9 position of the vanes of air passage 56 to selectively introduce exterior
10 air into plenum 51. The vanes of air passage 56 can preferably be
11 provided in a plurality of orientations between an open position and a
12 closed position to vary the amount of exterior fresh air introduced into
13 plenum 51 or the amount of air exhausted from plenum 51 responsive
14 to control from control system 30. Air circulated within plenum 51 can
15 comprise recirculated and/or fresh ambient air.

16 Utilizing temperature sensor 59, control system 30 can also
17 monitor the temperature of ambient air about housing 12. Control
18 system 30 can utilize such exterior temperature information from
19 temperature sensor 59 to control the operation of air passage 56.
20 Temperature sensor 59 is located adjacent air passage 56 in a preferred
21 embodiment.

22 As described in further detail below, control system 30 controls
23 air flow rates of fan 54 using fan control circuitry 48. Fan monitor
24 circuitry 49 provides air flow rate information to control system 30.

1 Control system 30 can monitor the total system voltage being delivered
2 via power bus 60 by summing the individual cell voltages. Control
3 system 30 can also monitor the electrical load being delivered via power
4 bus 60 using current sensor 40. With knowledge of the system bus
5 voltage and load, control system 30 can calculate waste thermal power
6 and provide a desired cooling air flow.

7 More specifically, the efficiency of one or more fuel cells may be
8 determined by dividing the respective fuel cell voltage by 1.23 (a
9 theoretical maximum voltage of a single fuel cell). An average
10 efficiency can be determined for all fuel cells 90 of fuel cell power
11 system 10. The remaining energy (energy not associated to electricity)
12 as determined from the efficiency calculation is waste thermal power.
13 The determined waste thermal power may be utilized to provide a
14 desired cooling air flow. Control system 30 controls the air flow rates
15 of fan 54 depending upon the waste thermal power in accordance with
16 one aspect of the described fuel cell power system 10.

17 During operation of fuel cell cartridges 14, non-fuel diluents such
18 as cathode-side water and atmospheric constituents can diffuse from the
19 cathode side of the fuel cell through a membrane electrode assembly
20 of the fuel cell and accumulate in the anode side of the fuel cell. In
21 addition, impurities in the fuel supply delivered directly to the anode
22 side of the fuel cell also accumulate. Without intervention, these
23 diluents can dilute the fuel sufficiently enough to degrade performance.
24 Accordingly, the anode side of the individual fuel cells is connected to

1 a bleed manifold 65. Bleed manifold 65 is additionally coupled with
2 bleed valve 43.

3 Control system 30 selectively operates bleed solenoid 42 to
4 selectively open and close bleed valve 43 permitting exhaustion of
5 matter such as entrained diluents and perhaps some fuel via a bleed
6 exhaust 66 within housing 12. Control system 30 can operate to open
7 and close bleed valve 43 on a periodic basis. The frequency of
8 openings and closings of bleed valve 43 can be determined by a number
9 of factors, such as electrical load coupled with terminals 62, 63, etc.
10 Although not shown, a fuel recovery system may be coupled with bleed
11 exhaust 66 to retrieve unused fuel for recirculation or other uses.

12 Following a start-up condition either inputted via interface or from
13 remote device 24, control system 30 selectively controls switching
14 device 38 to couple power bus 60 with positive terminal 62. Switching
15 device 38 can comprise parallel MOSFET switches to selectively couple
16 power bus 60 with an external load 22.

17 For example, control system 30 may verify when an appropriate
18 operational temperature within plenum 51 has been reached utilizing
19 temperature sensor 55. In addition, control system 30 can verify that
20 at least one electrical characteristic, such as voltage and/or current, of
21 respective fuel cell cartridges 14 has been reached before closing
22 switching device 38 to couple power bus 60 with an associated load 22.
23 Such provides proper operation of fuel cell power system 10 before
24 coupling bus 60 with an external load 22.

Power supply 32 includes power supplies having different voltage potentials in the described embodiment. For example, power supply 32 can provide a 5-volt supply voltage for operating the digital circuitry of fuel cell power system 10, such as control system 30. Power supply 32 can also provide higher voltage potentials, such as +/- 12 volts for operation of components such as fan 54 within fuel cell power system 10.

Further, power supply 32 can include a battery powering components during start-up procedures. Following start-up procedures, power supply 32 can be coupled with power bus 60 and internal power utilized by fuel cell power system 10 can be derived from electrical power generated from fuel cell cartridges 14. Charge circuitry 34 is provided to selectively charge batteries of power supply 32 utilizing power from power bus 60. Control system 30 is configured to monitor electrical conditions of the batteries and the supplied voltages of power supply 32 using power supply sensors 31. Control system 30 can operate charge circuitry 34 to charge batteries of power supply 32 depending upon such monitoring operations.

Control system 30 is also coupled with communication port 36 providing communications to an external device such as a remote device 24. An exemplary remote device 24 comprises an external control system or monitoring system off-site from fuel cell power system 10. Control system 30 can output data including requests, commands, operational conditions, etc., of fuel cell power system 10

1 using communication port 36. In addition, control system 30 can
2 receive data including commands, requests, etc., from remote device 24
3 using communication port 36.

4 Referring to Fig. 3, an exemplary fuel cell cartridge 14 is shown.
5 Further details of fuel cell cartridge 14 are disclosed in detail in U.S.
6 Patent Application Serial No. 08/979,853 incorporated by reference
7 above. The depicted fuel cell cartridge 14 includes a fuel distribution
8 frame 70 and a force application assembly which includes plural cathode
9 covers 71 which partially occlude respective cavities housing membrane
10 electrode assemblies (MEA) or membrane electrode diffusion assemblies
11 (MEDA) within fuel distribution frame 70. The depicted fuel cell
12 cartridge 14 includes four fuel cells (individually shown as reference
13 numeral 90 in Fig. 4). Other configurations are possible.

14 The respective cathode covers 71 individually cooperate or
15 otherwise mate with each other, and with the fuel distribution frame 70.
16 Individual apertures 72 which are defined by the cathode cover, define
17 passageways 73 which permit air from plenum 51 to circulate to the
18 cathode side of the membrane electrode diffusion assembly contained
19 within fuel distribution frame 70. The circulation of air through the
20 fuel cell cartridge 14 is discussed in significant detail in U.S. patent
21 application Serial No. 08/979,853 incorporated by reference above.

22 Conductive members 63 extend outwardly from a main body of
23 individual fuel cells within fuel cell cartridge 14. Conductive
24 members 63 are designed to extend through respective gaps or openings

1 which are provided in fuel distribution frame 70. Each conductive
2 member 63 is received between and thereafter electrically coupled with
3 pairs of conductive contacts which are mounted on a rear wall of a
4 subrack described in greater detail below.

5 Fuel cell cartridge 14 is operable to be serially electrically coupled
6 with a plurality of other fuel cell cartridges 14 by way of a subrack
7 which is generally indicated by the numeral 76. Subrack 76 has a main
8 body 77 having top and bottom portions 78, 79, respectively. The top
9 and bottom portions are joined together by a rear wall 80. Elongated
10 channels 81 are individually formed in top and bottom portions 78, 79
11 and are operable to slidably receive individual spines 74 which are
12 formed on fuel distribution frame 70.

13 Subrack 76 is made of a number of mirror image portions 85,
14 which when joined together, form the main body 77 of subrack 76.
15 These mirror image portions 85 are fabricated from a moldable
16 dielectric substrate. Power bus 60 is affixed on rear wall 80 of the
17 subrack 90. A repeating pattern of eight pairs of conductive
18 contacts 84 are attached on rear wall 80 and are coupled with power
19 bus 60. Electrical coupling of fuel cells within fuel cell cartridge 14
20 with power bus 60 is implemented using contacts 84 in the described
21 embodiment.

22 First and second conduits 86, 87 are also attached to rear wall 80
23 and are operable to matingly couple in fluid flowing relation to the fuel
24 distribution frame 70. The respective first and second conduits 86, 87

1 extend through rear wall 80 and connect with suitable external conduits
2 (not shown). First conduit 86 is coupled in fluid flowing relation with
3 fuel supply 23 (Fig. 1) and with anode sides of internal fuel cells.
4 Further, second conduit 87 exhausts from the anode sides of the fuel
5 cells to bleed manifold 65 (Fig. 2).

6 Individual fuel cell cartridges 14 may be selectively deactivated.
7 For example, fuel cell cartridges 14 are individually physically removable
8 from fuel cell power system 10. Removal of one or more fuel cell
9 cartridges 14 may be desired for maintenance, replacement, etc. of the
10 fuel cell cartridges 14. The remaining fuel cell cartridges 14 and
11 internal fuel cells thereof may continue to supply power to an
12 associated load 22 with one or more of the fuel cell cartridges 14
13 deactivated.

14 Individual contacts 84 may be configured to maintain electrical
15 continuity of bus 60 upon physical removal of a fuel cell cartridge 14
16 from an associated subrack 76. As shown, individual contacts 84
17 comprise make before break contacts which individually include plural
18 conductive members configured to receive an associated contact 69 of
19 a fuel cell cartridge 14. Individual contacts 69 can comprise a tang or
20 knife. Upon physical removal of fuel cell cartridge 14 and the
21 corresponding terminals 69, conductive members of contacts 84 are
22 mechanically coupled together to maintain a closed circuit within bus 60
23 intermediate terminals 62, 63. Such maintains a supply of electrical
24

1 power to load 22 coupled with terminals 62, 63 during removal of one
2 or more fuel cell cartridges 14 from fuel cell power system 10.

3 Referring to Fig. 4, a schematic representation of four fuel
4 cells 90 of a fuel cell cartridge 14 is shown. Individual fuel cells 90
5 have plural contacts 84 as described above. Fuel cells 90 are typically
6 coupled in series using power bus 60. Control system 30 is configured
7 to monitor at least one electrical characteristic of individual fuel
8 cells 90 using analysis circuitry 91 in the described embodiment.

9 More specifically, analysis circuitry 91 includes a voltage sensor 92
10 which may be provided electrically coupled with contacts 84 as shown.
11 Such coupling enables voltage sensor 92 to monitor the voltages of the
12 individual respective fuel cells 90. Fuel cells 90 have been observed
13 to typically produce a useful voltage of about 0.45 to about 0.7
14 volts DC under a typical load.

15 An exemplary configuration of voltage sensor 92 is implemented
16 as a differential amplifier for monitoring voltages. Voltage sensor 92
17 is preferably configured to monitor voltage magnitude across individual
18 fuel cells 90 as well as polarity of individual fuel cells 90.

19 Analysis circuitry 91 can additionally include plural current
20 sensors 94, 97. Individual current sensors may be coupled with
21 contacts 84 of individual fuel cells 90 to monitor current flowing
22 through respective individual fuel cells 90 in an alternative arrangement
23 (not shown). Control system 30 is coupled with current sensors 94, 97
24

1 and is configured to monitor corresponding respective currents through
2 fuel cells 90 and outputted to load 22 via bus 60.

3 Current sensor 94 is coupled intermediate one of fuel cells 90
4 and a coupling with internal power supply 93. Current sensor 94 is
5 coupled intermediate the coupling with internal power supply 93 and
6 external terminal 62 coupled with an associated load.

7 Following start-up operations, power for internal use within fuel
8 cell power system 10 (e.g., power provided to the circuitry of control
9 system 30) is provided from fuel cell cartridges 14. Internal power
10 supply 93 extracts current from bus 60 as shown to provide internal
11 power to fuel cell power system 10.

12 Accordingly, current sensor 94 provides information regarding
13 current flow through serially coupled fuel cell cartridges 14. Current
14 sensor 97 provides information regarding current flow to a load coupled
15 with terminal 62 (i.e., load 22 shown in Fig. 1).

16 Plural switching devices 96 are also provided which correspond to
17 respective fuel cells 90. Switching devices 96 can be individually
18 provided intermediate contacts 84 of respective fuel cells 90 as
19 illustrated. In the depicted configuration, switching devices 96 can
20 comprise MOSFET devices. Gate electrodes of switching devices 96 are
21 coupled with control system 30.

22 Control system 30 is operable to selectively shunt electrodes 84
23 using switching devices 96 corresponding to a desired one or more of
24 fuel cells 90 to electrically bypass or deactivate such fuel cells 90. For

1 example, if control system 30 observes that an electrical characteristic
2 (e.g., voltage) of a fuel cell 90 as sensed via sensors 92, 94 is below
3 a desired range, control system 30 can instruct a respective switching
4 device 96 to turn on and shunt the respective fuel cell 90. In
5 addition, individual fuel cells 90 can be selectively shunted using
6 respective switching devices 96 to enhance the performance of fuel
7 cells 90.

8 In one configuration, fuel cells 90 can be shunted according to
9 a duty cycle. The duty cycle may be adjusted by control system 30
10 depending upon operation of fuel cell cartridges 14 and fuel cell power
11 system 10. Fuel cells 90 can be shunted by sequential order as
12 determined by control system 30. Shunting is also helpful during start-
13 up operations to generate heat within housing 12 to bring fuel power
14 system 10 up to operating temperature in an expedient manner.

15 Alternatively, individual fuel cells 90 may be shunted for extended
16 periods of time if control system 30 observes such fuel cells are
17 operating below desired ranges (e.g., low voltage conditions, reverse
18 polarity conditions). Shunting operations are discussed in co-pending
19 U.S. Patent Application Serial No. 09/108,667, entitled Improved Fuel
20 Cell and Method for Controlling Same", filed on July 1, 1998, naming
21 William A. Fuglevand, Peter D. Devries, Greg A. Lloyd, David R. Lott,
22 and John P. Scartozzi as inventors, assigned to the assignee hereof,
23 having attorney docket number WA23-005, and incorporated herein by
24 reference.

Referring to Fig. 5, one configuration of control system 30 is illustrated. In the depicted arrangement, control system 30 includes a distributed control system including a plurality of controllers 100-120. Individual controllers 100-120 comprise programmable microcontrollers in the described embodiment. Exemplary microcontrollers have trade designation MC68HC705P6A available from Motorola, Inc. In the described embodiment, controllers 100-120 individually comprise a controller configured to execute instructions provided within executable code. In an alternative configuration, the steps described with reference to Figs. 16-28 below are implemented within hardware.

Individual controllers can include random access memory (RAM), read only memory (ROM), analog-to-digital (A/D) converters, serial input/output port (SIOP) communications, timers, digital input/output (I/O), timer interrupts and external interrupts. Individual controllers 102-120 have internal digital processing circuitry configured to execute a set of software or firmware instructions. Such instructions can be stored within the internal read only memory of the respective controllers 100-120. Other configurations of control system 30 are possible.

Among other functions, master controller 100 functions as a communication router to implement communications intermediate master controller 100 and individual slave controllers 102-120. In the described embodiment, communications are implemented in a limited full-duplex mode. Other communication protocols may be utilized.

1 Master controller 100 outputs messages to slave
2 controllers 102-120. Outputted messages are seen by all slave
3 controllers 102-120. Individual slaves 102-120 identified by the outgoing
4 message process the corresponding message. Thereafter, receiving slave
5 controllers 102-120 can output a message to master controller 100. In
6 addition, master controller 100 can sequentially poll slave
7 controllers 102-120 to determine whether such slave controllers 102-120
8 have communications for master controller 100. Master controller 100
9 can also supply clock information to slave controllers 102-120 to
10 establish a common timing reference within control system 30.

11 Individual slave controllers 102-120 perform specific tasks in
12 control system 30 including a plurality of distributed controllers.
13 Individual slave controllers 102-120 can monitor specified functions of
14 fuel cell power system 10 and report to master controller 100. Further,
15 master controller 100 can direct operations of individual slave
16 controllers 102-120.

17 Referring to Fig. 6, cartridge analysis slave controller 102 is
18 coupled with master controller 100 and associated circuitry. In
19 particular, cartridge analysis slave controller 102 is coupled with analysis
20 circuitry 91 which is in turn coupled with fuel cells 90 and power
21 bus 60 as previously described. Utilizing voltage sensor 92 and current
22 sensor 94 of analysis circuitry 91, cartridge analysis slave controller 102
23 can monitor electrical characteristics such as the voltage of individual
24 fuel cells 90 as well as the current through fuel cells 90. Further,

1 cartridge analysis slave controller 102 can monitor current flowing
2 through power bus 60 to load 22 using current sensor 97 of analysis
3 circuitry 91. As described below, cartridge analysis slave controller 102
4 can communicate such electrical characteristics to master controller 100.

5 Referring to Fig. 7, auxiliary valve slave controller 104 is shown
6 coupled with master controller 100 and auxiliary solenoids 44 and bleed
7 solenoid 42. In turn, auxiliary solenoids 44 are coupled with auxiliary
8 valves 45 and bleed solenoid 42 is coupled with bleed valve 43 as
9 discussed above. Responsive to control communications from master
10 controller 100, auxiliary valve slave controller 104 is configured to
11 operate auxiliary solenoids 44 and bleed solenoid 42 to control auxiliary
12 valves 45 and bleed valve 43, respectively.

13 Referring to Fig. 8, fan slave controller 106 is coupled with fan
14 control circuitry 48 and fan monitor circuitry 49. As described above,
15 fan control circuitry 48 and fan monitor circuitry 49 are individually
16 coupled with fan 54. Upon receiving instruction from master
17 controller 100, fan slave controller 106 is operable to control operation
18 of fan 54 using fan control circuitry 48. For example, fan slave
19 controller 106 controls on/off operational modes of fan 54 and the air
20 flow rate of fan 54. Using fan monitor circuitry 49, fan slave
21 controller 106 can monitor operation of fan 54. Fan slave
22 controller 106 can output fan status information (e.g., RPM for a
23 rotational fan) to master controller 100.
24

1 Referring to Fig. 9, interface slave controller 108 is coupled with
2 master controller 100 and operator interface 16. Master controller 100
3 supplies operational status information from other slave controllers to
4 interface slave controller 108. Thereafter, interface slave controller 108
5 can control operator interface 16 to convey such status information to
6 an operator. Exemplary indications can include a light emitting
7 diode (LED) array, bar graph display, audio warning buzzer, etc.

8 Referring to Fig. 10, external port slave controller 110 is coupled
9 with communication port 36 and memory 37 as well as master
10 controller 100. As described previously, communication port 36 is
11 additionally coupled with a remote device 24. Communication port 36
12 and memory 37 operate to provide bi-directional communications
13 intermediate external port slave controller 110 and remote device 24.
14 Although memory 37 is shown external of external port slave
15 controller 110, in some configurations such memory 37 can be
16 implemented as internal circuitry of external port slave controller 110.

17 Memory 37 operates to buffer data passing to remote device 24
18 or data received from remote device 24 within external port slave
19 controller 110. External port slave controller 110 operates to forward
20 received communications to master controller 100 according to timing of
21 master controller 100. External port slave controller 110 operates to
22 output messages from master controller 100 to remote device 24 using
23 communication port 36 according to an agreed-upon communication
24

1 protocol intermediate external port slave controller 110 and remote
2 device 24.

3 Referring to Fig. 11, system slave controller 112 is coupled with
4 master controller 100 as well as main solenoid 46, charge circuitry 34,
5 power supply sensors 31, current sensor 40 and element control
6 circuitry 41. Responsive to control from master controller 100, system
7 slave controller 112 is configured to control the operation of main
8 valve 47 using main solenoid 46. Further, responsive to control from
9 master controller 100, system slave controller 112 can selectively charge
10 a battery 35 of power supply 30 using charge circuitry 34.

11 Slave controller 112 can implement the charging of battery 35
12 responsive to information from power supply sensors 31. Power supply
13 sensors 31 provide electrical characteristic information of battery 35 and
14 internal power sources 39 to system slave controller 112. Internal
15 power sources 39 of power supply 32 include the 5 Volt DC source
16 and +/- 12 Volt DC source previously described.

17 Using current sensor 40, system slave controller 112 can monitor
18 current flowing through power bus 60. Such provides load information
19 and output power of fuel cell power system 10 to system slave
20 controller 112. Thereafter, system slave controller 112 can provide such
21 current and load information to master controller 100.

22 System slave controller 112 is also coupled with element control
23 circuitry 41 utilized to control modifying element 53. Such is utilized
24 to control the temperature within plenum 51. Modifying element 53

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1 can be controlled to provide circulated air within plenum 51 within a
2 desired operational temperature range. Modifying element 53 is
3 advantageously utilized in some start-up situations to bring the
4 temperature within plenum 51 within the operational range in an
5 expedient manner.

6 Referring to Fig. 12, sensor slave controller 114 is coupled with
7 master controller 100, heaters 74, 75, fuel detection circuitry 64 and
8 temperature circuitry 67. Fuel detection circuitry 64 is associated with
9 plural fuel sensors 58, 61 provided within housing 12 and plenum 51,
10 respectively. Temperature circuitry 67 is coupled with temperature
11 sensor 59 located outside of housing 12. Sensor slave 114 can control
12 heaters 74, 75 to selectively bring fuel sensors 58, 61 within an
13 appropriate temperature range for operation.

14 Fuel detection circuitry 64 receives data from fuel sensors 58, 61
15 and can condition such information for application to sensor slave
16 controller 114. If fuel is detected using fuel sensors 58, 61, fuel
17 detection circuitry 64 can process such information and provide such
18 data to sensor slave controller 114. Such information can indicate the
19 concentration of fuel detected within housing 12 or plenum 51 using
20 fuel sensors 58, 61, respectively. Sensor slave controller 114 can in
21 turn provide such information to master controller 100.

22 Temperature sensor 59 provides information regarding the
23 temperature of the surroundings of fuel cell power system 10.
24 Temperature circuitry 67 receives outputted signals from temperature

1 sensor 59 and can condition such signals for application to sensor slave
2 controller 114 monitoring the external temperature. Sensor slave
3 controller 114 can provide external temperature information to master
4 controller 100.

5 Referring to Fig. 13, air temperature slave controller 116 is
6 coupled with master controller 100 and temperature circuitry 68 and
7 passage control circuitry 57. Temperature circuitry 68 is associated with
8 temperature sensor 55 provided within plenum 51. Passage control
9 circuitry 57 operates to control air passage 56. For example, passage
10 control circuitry 57 can control the position of vanes of air passage 56
11 in an exemplary embodiment.

12 Temperature sensor 55 is positioned within plenum 51 to monitor
13 the temperature of circulated air within plenum 51. Temperature
14 circuitry 68 receives the sensor information from temperature sensor 55
15 and conditions the information for application to air temperature slave
16 controller 116. Thereafter, air temperature slave controller 116 may
17 operate to output the temperature information to master controller 100.

18 During operation of fuel cell power system 10, air temperature
19 slave controller 116 operates to control the flow of air into housing 12
20 using air passage 56 as well as the exhaustion of air within plenum 51
21 to the exterior of housing 12. Air temperature slave controller 116
22 controls air passage 56 using passage control circuitry 57 to maintain
23 the temperature of circulated air within plenum 51 within the desired
24 operational temperature range. Further, modifying element 63 of

Fig. 11 can be controlled as previously discussed to raise or lower the temperature of the circulated air. Such control of air passage 56 by air temperature slave controller 116 can be responsive to information from temperature sensor 55 and external temperature sensor 59. Further, efficiency information regarding fuel cells 90 can be calculated by air temperature slave controller 116 to determine waste thermal power. Air passage 56 may be controlled responsive to the calculated waste thermal power.

Referring to Fig. 14, shunt slave controller 118 is coupled with master controller 100 and switch control circuitry 95. Plural switching devices 96 are coupled with switch control circuitry 95. As described above, switching devices 96 are provided to implement selective shunting of respective fuel cells 90 of fuel cell cartridges 14. Master controller 100 can be configured to output shunt information to shunt slave controller 118 for selectively shunting using switching devices 96. Alternatively, shunt slave controller 118 can execute internally stored code to provide controlled selective shunting of switching devices 96.

Such shunting operations of fuel cells 90 can be utilized to provide increased power, to expedite start-up procedures, to shunt a faulty fuel cell cartridge 14, and to monitor for fuel leaks in exemplary embodiments. Switch control circuitry 95 is provided to provide conditioning of control signals intermediate shunt slave controller 118 and switching devices 96.

Referring to Fig. 15, switch slave controller 120 is coupled with master controller 100 and switch control circuitry 33 and switch conditioning circuitry 19. Switch control circuitry 33 is coupled with switching device 38 provided in series with power bus 60. Responsive to master controller 100, switch slave controller 120 can instruct switch controller circuitry 33 to control switching device 38. Switching device 38 provides selective coupling of power bus 60 to an external load 22. Such can be utilized to assure proper operation of fuel cell power system 10 prior to coupling power bus 60 with load 22.

Switch slave controller 120 can also monitor the status of operator interface switches 20 which may be set by an operator of fuel cell power system 10. Exemplary switches include power on/off of fuel cell power system 10, enable load, cartridge reset, etc. Switch conditioning circuitry 19 can filter signals provided from switches 20 and provide corresponding information regarding switch position to switch slave controller 120. Thereafter, switch slave controller 120 can output the switch status information to master controller 100.

Referring to Figs. 16-16A, a flow chart illustrating exemplary operations of master controller 100 of control system 30 is shown. Initially, master controller 100 performs a communications check at step S10. Communication checks may be implemented on a periodic interrupt basis to verify communications of master controller 100 and slave controllers 102-120.

1 At step S12, master controller 100 determines whether a
2 communication error was discovered. If such an error is present,
3 master controller 100 issues a shut down command to slave
4 controllers 102-120 at step S14. Respective slave controllers 102-120
5 implement shut down operations to bring fuel cell power system 10 into
6 a shut down condition. Interface slave controller 108 can indicate the
7 shut down status using operator interface 16. Further, master
8 controller 100 can instruct external port slave controller 110 to notify
9 remote device 24 of the shut down condition.

10 Alternatively, if no communication error is present in step S12,
11 master controller 100 instructs system slave controller 112 to open main
12 valve 47 at step S16. In addition, master controller 100 instructs fan
13 slave controller 106 to start fan 54 at step S16. At step S18, master
14 controller 100 instructs auxiliary valve slave controller 104 to open
15 auxiliary valves 45 using auxiliary solenoids 44. Next, master
16 controller 100 issues a command to auxiliary valve slave controller 104
17 to open bleed valve 43 using bleed solenoid 42 at step S20.

18 Thereafter, master controller 100 may execute a start-up subroutine
19 as set forth in Fig. 17 at step S22. Following successful execution of
20 the start-up subroutine, master controller 100 outputs a load enable
21 "ready" signal to switch slave controller 120 at step S24. Switch slave
22 controller 120 controls, using switch control circuitry 33, switching
23 device 38 to couple power bus 60 with an external load.
24

1 At step S26 of Fig. 16A, master controller 100 extracts data from
2 slave controllers 102-120. More specifically, master controller 100 can
3 receive information from cartridge analysis slave controller 102, auxiliary
4 valve slave controller 104, fan slave controller 106, external port slave
5 controller 110, system slave controller 112, sensor slave controller 114,
6 air temperature slave controller 116 and switch slave controller 120.

7 Next, master controller 100 proceeds to step S28 where it is
8 determined if a cartridge reset request has been issued. An operator
9 can implement a cartridge reset condition using switches 20. If a
10 cartridge reset is indicated, master controller 100 proceeds to step S30
11 and issues an on-line command to change the status of all off-line fuel
12 cell cartridges 14 to being on-line. Thereafter, master controller 100
13 initiates a bleed cycle utilizing auxiliary valve slave controller 104 at
14 step S32. During the bleed cycle, fuel may be applied to individual
15 fuel cell cartridges 14 and the bleed valve 43 can be opened to allow
16 exhaust operations using bleed manifold 65 and bleed exhaust 66.

17 If no cartridge reset request is indicated at step S28, or after the
18 bleed cycle is initiated at step S32, master controller 100 proceeds to
19 step S34 to determine whether a communication error is present. If
20 a communication error is present, master controller 100 issues a shut
21 down command at step S36.

22 If no communication error is present at step S34, master
23 controller 100 proceeds to step S38 to execute an error subroutine as
24 described in Figs. 18-18A below. At step S40, master controller 100

1 calculates operating parameters utilizing the data obtained at step S26.
2 Based upon the calculated operating parameters (e.g., setting of fan 54,
3 modifying element 53, etc.), master controller 100 sends the system
4 settings at step S42 to the appropriate slave controllers 102-120.

5 Referring to Fig. 17, a start-up subroutine executable by master
6 controller 100 is described. Initially, data from sensor slave
7 controller 114 is analyzed to determine whether the temperature within
8 plenum 51 is less than 15 °Celsius. If yes, master controller 100 turns
9 on modifying element 53 utilizing system slave controller 112 at
10 step S52. Alternatively, master controller 100 instructs systems slave
11 controller 112 to turn off modifying element 53 if appropriate at
12 step S54.

13 Thereafter, master controller 100 proceeds to step S56 and
14 instructs shunt slave controller 118 to set a shunting duty cycle to
15 maximum. At step S58, master controller 100 again retrieves the
16 temperature within plenum 51 from air temperature slave controller 116.
17 At step S58, master controller 100 determines whether the temperature
18 within plenum 51 is less than 30 °Celsius. If so, master controller
19 loops at step S58 until the temperature within plenum 51 is equal to
20 or greater 30 °Celsius. Next, at step S60, master controller 100 can
21 calculate a new duty cycle for application to shunt slave controllers 118.
22 Thereafter, master controller 100 returns to the main set of instructions
23 described in Figs 16-16A.
24

Referring to Figs. 18-18A, a flow chart illustrating exemplary error operations of master controller 100 is illustrated. Initially, at step S62, master controller 100 determines whether fan operation is proper. Master controller 100 observes data from fan slave controller 106 and outputs a fan error message to interface slave controller 108 at step S64 if fan operation is not proper. Thereafter, a shut down command is issued at step S66 to initiate a shut down procedure of fuel cell power system 10.

At step S68, it is determined whether internal power supplies are operating properly. More specifically, master controller 100 interfaces with system slave controller 112 to determine whether values monitored by power supply sensors 31 are within range. If not, master controller 100 sends a power supply error message to interface slave controller 108 at step S70. Thereafter, master controller 100 issues a shut down command at step S72.

At step S74, master controller 100 determines whether auxiliary valve operation is proper. Such is determined by data received from auxiliary valve slave controller 104 regarding the status of auxiliary valves 45. This can be additionally performed by monitoring the voltage of a deactivated fuel cell 90. A zero voltage should result if auxiliary valve operation is proper. Master controller 100 outputs an auxiliary valve error message at step S76 to interface slave controller 108 if operation is not proper. Such error message can thereafter be

1 displayed using operator interface 16. At step S78, master
2 controller 100 issues a shut down command.

3 Alternatively, master controller 100 proceeds to step S80 and
4 determines whether a major fuel leak is present. Such is determined
5 by monitoring data received from sensor slave controller 114 responsive
6 to the monitoring of fuel sensors 58, 61. If a major fuel leak is
7 detected, master controller 100 sends a major fuel leak error message
8 to interface slave controller 108 at step S82. Thereafter, a shut down
9 command is issued at step S84.

10 If no major fuel leak is determined, master controller 100
11 proceeds to step S86 to determine whether a minor fuel leak is present.
12 In one configuration, a major fuel leak may be defined as ≥ 5000 ppm
13 and a minor fuel leak may be defined as 1000-4999 ppm. In some
14 applications, the ranges may be varied for increased or decreased
15 sensitivity to fuel.

16 If a minor fuel leak is determined at step S86, master
17 controller 100 proceeds to step S88 to try to determine if one of fuel
18 cell cartridges 14 is faulty and the source of the fuel leak.
19 Accordingly, a first fuel cell cartridge 14 is deactivated at step S88.
20 Next, master controller 100 attempts to determine whether the fuel leak
21 is gone. Deactivation of the fuel cell cartridge 14 ceases the supply
22 of fuel to the fuel cell cartridge 14 using the appropriate auxiliary
23 valve 45. If it is determined that the fuel leak is gone, an error
24

1 message is sent at step S92 to interface slave controller 108 for
2 conveyance to operator interface 16.

3 If the fuel leak remains as determined at step S90, master
4 controller 100 proceeds to step S94 to reactivate the previously
5 deactivated fuel cell cartridge 14 and deactivate a subsequent fuel cell
6 cartridge 14. At step S96, master controller 100 determines whether an
7 index has led past the last fuel cell cartridge 14. If not, master
8 controller 100 returns to steps S90-S94 to continue with the minor leak
9 analysis. Alternatively, master controller 100 proceeds to step S98 and
10 ignores the minor leak for a specified period of time. Once the
11 specified period of time has elapsed, and the fuel leak is still present,
12 master controller 100 can issue a shut down command which will cease
13 the supply of fuel from fuel supply 23 into housing 12 using main
14 valve 47.

15 At step S100, master controller 100 determines whether there is
16 a failed fuel cell cartridge 14. If so, master controller 100 shuts off
17 the supply fuel to the failed fuel cell cartridge 14 using the appropriate
18 auxiliary valve 45 at step S102. In addition, a full-time shunt command
19 for the failed fuel cell cartridge 14 is applied to shunt slave
20 controller 118 at step S104. At step S106, master controller 100 sends
21 an error message to interface slave controller 108 for conveyance using
22 operator interface 16.

23 At step S108, master controller 100 determines whether enough
24 fuel cell cartridges 14 are currently on-line. In one exemplary

1 arrangement, master controller 100 determines whether less than eight
2 fuel cell cartridges 14 are on-line. If not enough cartridges are on-line,
3 master controller 100 sends an error command at step S110 to interface
4 slave controller 108. Such error message can be conveyed to an
5 operator using operator interface 16. Next, at step S112, master
6 controller 100 issues a shut down command for fuel cell power
7 system 10. If enough fuel cell cartridges 14 are on-line at step S108,
8 master controller 100 proceeds to the main set of instructions defined
9 in the flow chart of Figs. 16-16A.

10 Referring to Figs. 19-19B, a flow chart illustrating exemplary
11 operations of cartridge analysis slave controller 102 is shown. Initially,
12 at step S120, slave controller 102 indexes to a first fuel cell 90 within
13 fuel cell power system 10. A transient counter described below is
14 cleared at step S121. Slave controller 102 obtains a voltage reading of
15 the indexed fuel cell 90 at step S122. At step S124, slave
16 controller 102 determines whether the polarity of the indexed fuel
17 cell 90 is proper. If not, slave controller 102 proceeds to step S126
18 and sets the indicated fuel cell voltage to zero. Thereafter, the voltage
19 for the currently indexed fuel cell 90 is posted to a fuel cell array at
20 step S134.

21 Alternatively, if the polarity of the indexed fuel cell 90 is proper
22 at step S124, slave controller 102 determines whether the voltage is
23 proper at step S128. If not, slave controller 102 increments a ride-
24 through transient counter at step S130. Thereafter, slave controller 102

determines whether the transient counter is at a maximum value at step S132. If not, slave controller 102 returns to step S122. If the transient counter has reached a maximum value, slave controller 102 proceeds to step S134 to post the voltage to the fuel cell array.

At step S136, slave controller 102 determines whether all of the fuel cells 90 have been indexed. If not, slave controller 102 indexes to a next fuel cell 90 at step S138 and thereafter returns to step S122. If all fuel cells 90 have been analyzed using analysis circuitry 91, slave controller 102 proceeds to step S140 to arrange the fuel cell readings into readings for respective fuel cell cartridges 14.

Next, slave controller 102 proceeds to step S141 to index to a first of fuel cell cartridges 14. Slave controller 102 then proceeds to step S142 to determine whether any of the fuel cell cartridges 14 were previously provided in a down or off-line condition. If so, slave controller 102 proceeds to step S160 to determine whether the last fuel cell cartridge 14 has been indexed. Otherwise, slave controller 102 proceeds to step S144 to determine whether a voltage of any of the fuel cells of a currently indexed fuel cell cartridge 14 have an unacceptable voltage condition (e.g., low voltage). If so, slave controller 102 increments a low voltage counter at step S146. Next, slave controller 102 proceeds to step S148 to determine whether the low voltage counter is at a maximum value. The maximum value is selected to provide the unacceptable fuel cell with a chance to recover and provide an acceptable voltage during a subsequent pass through the flow

chart. If the low voltage counter is at maximum, slave controller 102 proceeds to step S150 to set the currently indexed fuel cell cartridge 14 status as deactivated (e.g., down or off-line). Slave controller 102 instructs master controller 100 to shut off fuel to the currently indexed fuel cell cartridge 14 at step S152. Master controller 100 thereafter instructs auxiliary valve slave controller 104 to shut off fuel to the respective fuel cell cartridge 14. At step S154, master controller 100 additionally outputs a command to shunt slave controller 118 to shunt the appropriate fuel cell cartridge 14. Also, master controller 100 can output the message to interface slave controller 108 to convey the status of the currently indexed fuel cell cartridge 14 using operator interface 16.

If the currently indexed fuel cell cartridge 14 has a proper voltage as determined at step S144, slave controller 102 proceeds to step S145 to clear the low voltage counter. Slave controller 102 associates the fuel cells with respective low voltage counter values. The low voltage counter for a given fuel cell previously determined to be unacceptable during the current pass through the flow chart is cleared at step S145 if the voltage is deemed acceptable at step S144.

Slave controller 102 proceeds to step S156 to post high and low voltages of the fuel cells of the currently indexed fuel cell cartridge 14 to memory. At step S158, slave controller 102 outputs the high and low voltage information of the fuel cells of the fuel cell cartridge 14 to master controller 100. Master controller 100 processes the high and

low voltages for the fuel cell cartridge 14 and can instruct interface slave controller 108 to display or otherwise convey the voltages to an operator using operator interface 16.

At step S160, slave controller 102 determines whether the last fuel cell cartridge 14 has been indexed. If not, slave controller 102 indexes to a next fuel cell cartridge 14 at step S162 and thereafter returns to step S142. If the last fuel cell cartridge 14 has been indexed at step S160, slave controller 102 proceeds to step S164 to determine whether too many fuel cell cartridges 14 are down (e.g., less than seven fuel cell cartridges 14 are down or off-line). If so, slave controller 102 sends an appropriate message to master controller 100 at step S166.

At step S168, slave controller 102 monitors for the reception of messages from master controller 100. If a message is received, slave controller 102 processes the incoming message at step S170. At step S172, slave controller 102 can transmit fuel cell data and any messages. Thereafter, slave controller 102 returns to step S120 to index the first fuel cell 90 to repeat the analysis.

Referring to Figs. 20-20A, a flow chart illustrating exemplary operations of auxiliary valve slave controller 104 is shown. Initially, slave controller 104 performs a communication check at step S180 to assure proper communications with master controller 100. At step S182, slave controller 104 listens for a start-up signal from master controller 100. At step S184, it is determined whether the appropriate start-up signal has been received. Once the start-up signal is received,

1 slave controller 104 instructs auxiliary solenoids 44 to open respective
2 auxiliary valves 45 at step S186. At step S188, slave controller 104
3 commences to perform a bleed procedure wherein slave controller 104
4 instructs bleed solenoid 42 to open bleed valve 43 for a defined length
5 of time.

6 At step S190, slave controller 104 reads data and messages from
7 master controller 100. Slave controller 104 determines whether the
8 master is off-line at step S192. If so, slave controller 104 closes
9 auxiliary valves 45 at step S194. Otherwise, slave controller 104
10 proceeds to step S196 to determine whether a shut down request has
11 been issued by master controller 100. If so, slave controller 104
12 proceeds to step S194. Otherwise, slave controller 104 proceeds to
13 step S198 to determine whether a change in status of any fuel cell
14 cartridges 14 has been made. If so, slave controller 104 controls
15 respective auxiliary valves 45 at step S200 to either supply fuel if the
16 corresponding fuel cell cartridge 14 is on-line, or cease supply of fuel
17 if the fuel cell cartridge 14 has been taken off-line.

18 At step S202, slave controller 104 monitors to determine whether
19 it is time for a bleed cycle. Slave controller 104 can be configured to
20 periodically implement a bleed cycle using bleed solenoid 42 and bleed
21 valve 43 according to a bleed timer. If it is time for a bleed cycle,
22 slave controller 104 proceeds to step S204 to reset the bleed timer and
23 thereafter commence a bleed procedure at step S206. As shown, slave
24

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1 controller 104 cycles back to step S190 to read any new data from
2 master controller 100.

3 Referring to Figs. 21-21A, a flow chart illustrating exemplary
4 operations of fan slave controller 106 is illustrated. Slave controller 106
5 initially proceeds to step S210 and performs a communications check to
6 verify proper communications with master controller 100. At step S212,
7 slave controller 106 listens for an appropriate fan start-up signal from
8 master controller 100.

9 Once the appropriate start-up signal is received as determined at
10 step S214, slave controller 106 proceeds to step S216 to start operation
11 of fan 54 at a maximum air flow setting. Thereafter, slave
12 controller 106 reads fan status information from fan monitoring
13 circuitry 49 at step S218. At step S220, slave controller 106 determines
14 whether fan 54 is operating properly. If not, slave controller 106 issues
15 a shut down request to master controller 100 at step S222.

16 Otherwise, slave controller 106 receives any updated fan setting
17 from master controller 100 at step S224. At step S226, slave
18 controller 106 can output appropriate signals to fan control circuitry 48
19 to adjust the operation of fan 54. At step S228, slave controller 106
20 determines whether a shut down command has been issued by master
21 controller 100. If not, slave controller 106 returns to step S218 to
22 read the status of fan 54. Otherwise, slave controller 106 proceeds to
23 step S230 to shut off fan 54.
24

Referring to Fig. 22, a flow chart illustrating exemplary operations of interface slave controller 108 is shown. Initially, slave controller 108 proceeds to step S240 to perform a communications check with master controller 100. Thereafter, slave controller 108 outputs appropriate message information to operator interface 16 for conveyance to an operator. In the described embodiment, operator interface 16 displays the message information received from master controller 100.

Slave controller 108 listens for updates to operator interface 16 at step S244. At step S246, it is determined whether master controller 100 is off-line. If so, slave controller 108 sends an error message to operator interface 16 to indicate master controller 100 is off-line. Otherwise, slave controller 108 proceeds to step S250 to determine whether there was a change in the status of operator interface 16. If not, slave controller 108 proceeds to step S244 and listens for updates for operator interface 16. If a change in interface status is indicated at step S250, slave controller 108 proceeds to step S252 to update operator interface 16.

Referring to Fig. 23, a flow chart illustrating exemplary operations of external port slave controller 110 is illustrated. Initially, slave controller 110 performs a communications check with master controller 100 at step S260. Thereafter, slave controller 100 reads any input communication from remote device 24 and communication port 36. At step S264, slave controller 110 sends any received communications to master controller 100. At step S266, slave controller 110 receives

any communications from master controller 100. Slave controller 110 proceeds to forward any communications to communication port 36 and remote device 24 at step S268.

Referring to Figs. 24-24A, a flow chart illustrating exemplary operations of system slave controller 112 is shown. Initially, at step S270, slave controller 112 performs a communications check with master controller 100. Next, slave controller 112 can read status information from power supply sensors 31 and current sensor 40 at step S272. At step S274, it is determined by slave controller 112 whether the inputted status values are within appropriate ranges. If not, slave controller 112 can generate an error message at step S276 for application to master controller 100.

Otherwise, slave controller 112 proceeds to step S278 and listens for a main valve open command from master controller 100. At step S280, it is determined whether the open valve command was received. Once the open valve command is received, slave controller 112 proceeds to step S282 to activate main valve 47 using main solenoid 46. At step S284, slave controller 112 listens for a shut down command from master controller 100.

Proceeding to step S286, slave controller 112 determines whether the master controller 100 is off-line. If so, slave controller 112 proceeds to step S296 to shut off power supply 32 and main valve 47 using main solenoid 46. If master controller 100 is on-line, slave controller 112 proceeds to step S288 to again read status values from

1 power supply sensors 31 and current sensor 40. Slave controller 112
2 can control charge circuitry 34 to charge battery 35, if necessary, at
3 step S290 responsive to the values read at step S288.

4 At step S292, slave controller 112 determines whether the values
5 are within the appropriate ranges. If not, slave controller 112 proceeds
6 to step S294 to generate an error message for application to master
7 controller 100. Otherwise, at step S296, slave controller 112 monitors
8 for the presence of a shut down command or request from master
9 controller 100. If no shut down command is issued, slave
10 controller 112 returns to step S284. If a shut down request or
11 command is received at step S296, slave controller 112 proceeds to
12 step S296 to shut off main valve 47 using main solenoid 46 as well as
13 turn off power supply 32.

14 Referring to Fig. 25, a flow chart illustrating exemplary operations
15 of sensor slave controller 114 is shown. Initially, at step S300, slave
16 controller 114 performs a communication check with master
17 controller 100. At step S302, slave controller 114 controls
18 heaters 74, 75, if necessary, to bring associated fuel sensors 58, 61
19 within proper operating temperature ranges. Thereafter, slave
20 controller 114 is configured to read information from fuel detection
21 circuitry 64 and corresponding fuel sensors 58, 61.

22 Responsive to reading the fuel sensor values, slave controller 114
23 determines at step S306 whether a major leak was detected. If so,
24 slave controller 114 forwards an appropriate major leak message to

1 master controller 100 at step S308. At step S310, the fuel sensor
2 values are analyzed to determine whether a minor leak was detected.
3 If so, slave controller 114 sends an appropriate minor leak message to
4 master controller 100 at step S312.

5 At step S314, slave controller 114 reads external temperature
6 information from temperature circuitry 67 and associated temperature
7 sensor 59. At step S316, slave controller 114 sends external
8 temperature values to master controller 100.

9 Referring to Fig. 26, a flow chart illustrating exemplary operations
10 of air temperature slave controller 116 is shown. Initially, slave
11 controller 116 performs a communication check with master
12 controller 100 at step S320. Thereafter, slave controller 116 reads
13 temperature values from temperature circuitry 68 and associated
14 temperature sensor 55 located within air plenum 51. At step S324,
15 slave controller 116 reads a temperature set point as calculated from
16 master controller 100.

17 At step S326, slave controller 116 sets recirculation using air
18 passage 56 and fan 54 to maintain a set point temperature. Slave
19 controller 116 outputs the air temperature of plenum 51 as determined
20 by temperature sensor 55 to master controller 100 at step S328.

21 Referring to Fig. 27, a flow chart illustrating exemplary operations
22 of shunt slave controller 118 is shown. Initially, at step S330, slave
23 controller 118 performs a communication check with master
24

1 controller 100. At step S332, slave controller 118 reads data from
2 master controller 100.

3 At step S334, it is determined whether there was a change in
4 status of the fuel cell cartridges 14. If so, slave controller 118
5 proceeds to step S336 to determine whether there is a change of any
6 of the fuel cell cartridges 14 to an off-line condition. If not, the
7 appropriate switching device 96 for the respective fuel cell cartridge 14
8 is latched to an off position at step S338. Alternatively, slave
9 controller 118 proceeds to step S340 to latch the appropriate switching
10 device 96 for the respective fuel cell cartridge 14 in an on position.

11 Following processing of steps S338 or S340, or alternatively if
12 there is no change in status of fuel cell cartridges 14 as determined at
13 step S334, slave controller 118 proceeds to step S342 to cyclically shunt
14 fuel cells 90 within fuel cell cartridges 14 as described in detail in U.S.
15 Patent Application Serial No. 09/108,667 incorporated by reference
16 above.

17 Referring to Fig. 28, a flow chart illustrating exemplary operations
18 of switch slave controller 120 is shown. Slave controller 120 performs
19 a communication check with master controller 100 at step S350.
20 Thereafter, slave controller 120 reads switch status information from
21 switches 20 and switch conditioning circuitry 19 at step S352. At
22 step S354, slave controller 120 reads load enable status information from
23 master controller 100.
24

1 Slave controller 120 determines whether a power off request was
2 received from master controller 100 at step S356. If yes, slave
3 controller 120 proceeds to step S358 to send a shut down message to
4 master controller 100. Otherwise, slave controller 120 proceeds to
5 step S360. Slave controller 120 determines whether a load enable
6 request was provided from switches 20. If so, slave controller 120
7 proceeds to step S362 to determine whether master controller 100 has
8 indicated fuel cell power system 10 is ready to provide power as
9 determined in step S354. If so, slave controller 120 proceeds to
10 step S364 to enable switching device 38.

11 At step S366, slave controller 120 determines whether the master
12 controller 100 is in an off-line condition. If so, slave controller 120
13 disables switching device 38 at step S368. Otherwise, slave
14 controller 120 proceeds to step S370 to determine whether a cartridge
15 reset has been indicated from switches 20. If so, slave controller 120
16 proceeds to send a cartridge reset message to master controller 100 at
17 step S372. Slave controller 120 then returns to step S352 to read
18 switch status from switch conditioning circuitry 19 and associated
19 switches 20 at step S352.

20 In compliance with the statute, the invention has been described
21 in language more or less specific as to structural and methodical
22 features. It is to be understood, however, that the invention is not
23 limited to the specific features shown and described, since the means
24 herein disclosed comprise preferred forms of putting the invention into

1 **CLAIMS:**

2 1. A fuel cell power system comprising:

3 a plurality of fuel cells electrically coupled with plural terminals
4 and individually configured to convert chemical energy into electricity;
5 and

6 a digital control system configured to at least one of control and
7 monitor an operation of the fuel cells.
8

9 2. The fuel cell power system according to claim 1 wherein the
10 control system is configured to control the operation.
11

12 3. The fuel cell power system according to claim 1 wherein the
13 control system is configured to monitor the operation.
14

15 4. The fuel cell power system according to claim 1 wherein the
16 fuel cells are coupled in series.
17

18 5. The fuel cell power system according to claim 1 wherein the
19 control system comprises a plurality of distributed controllers.
20

21 6. The fuel cell power system according to claim 5 wherein the
22 distributed controllers are configured in a master\slave relationship.
23
24

1 13. The fuel cell power system according to claim 1 further
2 comprising:

3 a housing about the fuel cells;

4 a temperature sensor within the housing; and

5 an air temperature control assembly configured to at least one of
6 increase and decrease the temperature in the housing.

7
8 14. The fuel cell power system according to claim 13 wherein
9 the control system is configured to monitor temperature using the
10 temperature sensor and to control the air temperature control assembly
11 responsive to the monitoring to maintain the temperature within the
12 housing within a predefined range.

13
14 15. The fuel cell power system according to claim 13 wherein
15 the control system is configured to monitor temperature using the
16 temperature sensor and to control the air temperature control assembly
17 responsive to the monitoring to maintain the temperature within the
18 housing within a predefined range of approximately 25 °Celsius
19 to 80 °Celsius.

20
21 16. The fuel cell power system according to claim 1 further
22 comprising a fan configured to direct air to the fuel cells, and the
23 control system is configured to control the fan.
24

17. The fuel cell power system according to claim 1 further comprising a plurality of valves configured to supply fuel to respective fuel cells, and the control system is configured to control the valves.

18. The fuel cell power system according to claim 1 further comprising a main valve configured to supply fuel to the fuel cells, and the control system is configured to control the main valve.

19. The fuel cell power system according to claim 1 further comprising a communication port adapted to couple with a remote device, and the control system is configured to communicate with the remote device via the communication port.

20. The fuel cell power system according to claim 19 wherein the shut down operation deactivates one or more of the fuel cells.

21. The fuel cell power system according to claim 19 wherein the shut down operation deactivates all the fuel cells.

22. The fuel cell power system according to claim 1 further comprising a switching device intermediate one of the terminals and the fuel cells, and the control system is configured to control the switching device.

1 23. The fuel cell power system according to claim 1 further
2 comprising:

3 a housing about the fuel cells; and

4 a fuel sensor configured to monitor for the presence of fuel
5 within the housing, and the control system is coupled with the fuel
6 sensor and configured to implement a shut down operation responsive
7 to a detection of fuel within the housing.

8
9 24. The fuel cell power system according to claim 1 wherein the
10 fuel cells are provided in a plurality of cartridges.

11
12 25. A fuel cell power system comprising:

13 a housing;

14 a plurality of terminals;

15 a plurality of fuel cells within the housing and electrically coupled
16 with the terminals and configured to convert chemical energy into
17 electricity;

18 a plurality of valves adapted to couple with a fuel source and
19 configured to selectively supply fuel to respective fuel cells; and

20 a control system configured to control the plurality of valves.

21
22 26. The fuel cell power system according to claim 25 wherein
23 the control system comprises a plurality of distributed controllers.
24

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1 27. The fuel cell power system according to claim 25 wherein
2 the fuel cells comprise polymer electrolyte membrane fuel cells.

3
4 28. The fuel cell power system according to claim 25 wherein
5 the fuel cells are configured to be individually selectively deactivated
6 and remaining ones of the fuel cells are configured to provide electricity
7 to the terminals with others of the fuel cells deactivated.

8
9 29. The fuel cell power system according to claim 28 wherein
10 the fuel cells are individually configured to be physically removable.

11
12 30. The fuel cell power system according to claim 28 wherein
13 the fuel cells are individually configured to be electrically bypassed.

14
15 31. The fuel cell power system according to claim 25 wherein
16 the control system is configured to monitor at least one electrical
17 characteristic of the fuel cells and to control the respective valves
18 responsive to the monitoring.

1 32. A fuel cell power system comprising:
2 a housing;
3 a plurality of terminals;
4 at least one fuel cell within the housing and electrically coupled
5 with the terminals and configured to convert chemical energy into
6 electricity;
7 a bleed valve configured to selectively purge matter from the at
8 least one fuel cell; and
9 a control system configured to control selective positioning of the
10 bleed valve.

11
12 33. The fuel cell power system according to claim 32 wherein
13 the control system comprises a plurality of distributed controllers.

14
15 34. The fuel cell power system according to claim 32 wherein
16 the at least one fuel cell comprises a plurality of polymer electrolyte
17 membrane fuel cells.

18
19 35. The fuel cell power system according to claim 32 wherein
20 the at least one fuel cell comprises a plurality of fuel cells.

1 36. The fuel cell power system according to claim 35 wherein
2 the fuel cells are configured to be individually selectively deactivated
3 and remaining ones of the fuel cells are configured to provide electricity
4 to the terminals with others of the fuel cells deactivated.

5
6 37. The fuel cell power system according to claim 32 wherein
7 the control system is configured to periodically open the bleed valve.

8
9 38. The fuel cell power system according to claim 32 further
10 comprising a connection arranged to provide drainage from an anode
11 side of the at least one fuel cell to the bleed valve.

12
13 39. A fuel cell power system comprising:
14 a housing;
15 a plurality of terminals;
16 at least one fuel cell within the housing and electrically coupled
17 with the terminals and configured to convert chemical energy into
18 electricity;
19 a fan within the housing and configured to direct air to the at
20 least one fuel cell; and
21 a control system configured to control an operation of the fan.

22
23 40. The fuel cell power system according to claim 39 wherein
24 the control system comprises a plurality of distributed controllers.

1 41. The fuel cell power system according to claim 39 wherein
2 the at least one fuel cell comprises a plurality of polymer electrolyte
3 membrane fuel cells.

4
5 42. The fuel cell power system according to claim 39 wherein
6 the at least one fuel cell comprises a plurality of fuel cells.

7
8 43. The fuel cell power system according to claim 42 wherein
9 the fuel cells are configured to be individually selectively deactivated
10 and remaining ones of the fuel cells are configured to provide electricity
11 to the terminals with others of the fuel cells deactivated.

12
13 44. The fuel cell power system according to claim 39 further
14 comprising at least one sensor configured to at least one of monitor
15 current supplied to a load coupled with the terminals and monitor
16 voltage of the at least one fuel cell, and the control system is
17 configured to control a rate of air flow of the fan responsive to the
18 monitoring.

19
20 45. The fuel cell power system according to claim 39 wherein
21 the at least one fuel cell includes a cathode side and the fan and the
22 housing are configured to direct air into the cathode side of the at
23 least one fuel cell.

24

1 46. The fuel cell power system according to claim 39 further
2 comprising a plenum within the housing and configured to direct air
3 from the fan to the at least one fuel cell.

4
5 47. The fuel cell power system according to claim 46 wherein
6 the plenum is configured to direct air to a cathode side of the at least
7 one fuel cell.

8
9 48. The fuel cell power system according to claim 39 further
10 comprising an air flow device configured to operate responsive to
11 control from the control system to permit selective passage of air at
12 least one of into and out of the housing.

13
14 49. The fuel cell power system according to claim 39 further
15 comprising monitoring circuitry configured to monitor an air flow rate
16 of the fan and output a signal indicative of the air flow rate to the
17 control system.

18
19 50. The fuel cell power system according to claim 49 wherein
20 the control system is configured to control an air flow rate of the fan.
21
22
23
24

1 51. A fuel cell power system comprising:
2 a housing;
3 a plurality of terminals;
4 at least one fuel cell within the housing and electrically coupled
5 with the terminals and configured to convert chemical energy into
6 electricity;
7 a control system configured to at least one of control and monitor
8 an operation of the at least one fuel cell; and
9 an operator interface coupled with the control system to indicate
10 at least one operational status responsive to control from the control
11 system.

12
13 52. The fuel cell power system according to claim 51 wherein
14 the control system comprises a plurality of distributed controllers.

15
16 53. The fuel cell power system according to claim 51 wherein
17 the at least one fuel cell comprises a plurality of polymer electrolyte
18 membrane fuel cells.

19
20 54. The fuel cell power system according to claim 51 wherein
21 the at least one fuel cell comprises a plurality of fuel cells.

22
23
24

1 55. The fuel cell power system according to claim 54 wherein
2 the fuel cells are configured to be individually selectively deactivated
3 and remaining ones of the fuel cells are configured to provide electricity
4 to the terminals with others of the fuel cells deactivated.

5
6 56. The fuel cell power system according to claim 51 wherein
7 the operator interface is positioned for observation from the exterior of
8 the housing.

9
10 57. The fuel cell power system according to claim 51 wherein
11 the operator interface comprises a display configured to emit a human
12 perceptible signal.

13
14 58. The fuel cell power system according to claim 51 wherein
15 the operator interface comprises interface switches configured to receive
16 operator inputs.

17
18 59. A fuel cell power system comprising:
19 a plurality of terminals;
20 at least one fuel cell electrically coupled with the terminals and
21 configured to convert chemical energy into electricity;
22 a power supply configured to selectively supply electricity; and
23 a control system configured to monitor at least one operational
24 condition of the power supply.

60. The fuel cell power system according to claim 59 wherein the control system comprises a plurality of distributed controllers.

61. The fuel cell power system according to claim 59 wherein the at least one fuel cell comprises a plurality of polymer electrolyte membrane fuel cells.

62. The fuel cell power system according to claim 59 wherein the at least one fuel cell comprises a plurality of fuel cells.

63. The fuel cell power system according to claim 62 wherein the fuel cells are configured to be individually selectively deactivated and remaining ones of the fuel cells are configured to provide electricity to the terminals with others of the fuel cells deactivated.

64. The fuel cell power system according to claim 59 wherein the power supply supplies electricity to the control system.

65. The fuel cell power system according to claim 59 wherein the power supply includes a battery.

66. The fuel cell power system according to claim 65 further comprising charge circuitry configured to selectively charge the battery responsive to control from the control system.

1 67. The fuel cell power system according to claim 59 further
2 comprising an operator interface and the control system is configured
3 to control the operator interface to indicate the at least one operational
4 condition.

5
6 68. A fuel cell power system comprising:
7 a plurality of terminals;
8 at least one fuel cell electrically coupled with the terminals and
9 configured to convert chemical energy into electricity;
10 a sensor configured to monitor at least one electrical condition of
11 the at least one fuel cell; and
12 a control system coupled with the sensor and configured to
13 monitor the sensor.

14
15 69. The fuel cell power system according to claim 68 wherein
16 the control system comprises a plurality of distributed controllers.

17
18 70. The fuel cell power system according to claim 68 wherein
19 the at least one fuel cell comprises a plurality of polymer electrolyte
20 membrane fuel cells.

21
22 71. The fuel cell power system according to claim 68 wherein
23 the at least one fuel cell comprises a plurality of fuel cells.

24

1 72. The fuel cell power system according to claim 71 wherein
2 the fuel cells are configured to be individually selectively deactivated
3 and remaining ones of the fuel cells are configured to provide electricity
4 to the terminals with others of the fuel cells deactivated.

5
6 73. The fuel cell power system according to claim 68 further
7 comprising an operator interface and the control system is configured
8 to control the operator interface to indicate the at least one electrical
9 condition.

10
11 74. The fuel cell power system according to claim 68 further
12 comprising a fan configured to direct air to the at least one fuel cell
13 and the control system is configured to control the fan responsive to
14 the at least one electrical condition.

15
16 75. A fuel cell power system comprising:
17 a plurality of terminals;
18 a plurality of fuel cells electrically coupled with the terminals and
19 configured to convert chemical energy into electricity;
20 a main valve adapted to couple with a fuel source and configured
21 to selectively supply fuel to the fuel cells; and
22 a control system configured to control the main valve.
23
24

1 76. The fuel cell power system according to claim 75 wherein
2 the control system comprises a plurality of distributed controllers.

3
4 77. The fuel cell power system according to claim 75 wherein
5 the fuel cells comprise polymer electrolyte membrane fuel cells.

6
7 78. The fuel cell power system according to claim 75 wherein
8 the fuel cells are configured to be individually selectively deactivated
9 and remaining ones of the fuel cells are configured to provide electricity
10 to the terminals with others of the fuel cells deactivated.

11
12 79. The fuel cell power system according to claim 75 further
13 comprising a plurality of auxiliary valves configured to selectively supply
14 fuel to respective fuel cells.
15
16
17
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80. A fuel cell power system comprising:

- a housing;
- a plurality of terminals;
- at least one fuel cell within the housing and electrically coupled with the terminals and configured to convert chemical energy into electricity;

an air temperature control assembly configured to direct air within the housing to the at least one fuel cell and comprising a modifying element configured to condition the temperature of the air; and

a control system configured to control the modifying element.

81. The fuel cell power system according to claim 80 wherein the control system comprises a plurality of distributed controllers.

82. The fuel cell power system according to claim 80 wherein the at least one fuel cell comprises a plurality of polymer electrolyte membrane fuel cells.

83. The fuel cell power system according to claim 80 wherein the at least one fuel cell comprises a plurality of fuel cells.

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1 84. The fuel cell power system according to claim 83 wherein
2 the fuel cells are configured to be individually selectively deactivated
3 and remaining ones of the fuel cells are configured to provide electricity
4 to the terminals with others of the fuel cells deactivated.

5
6 85. The fuel cell power system according to claim 80 further
7 comprising a temperature sensor configured to monitor the temperature
8 of the directed air within the housing.

9
10 86. The fuel cell power system according to claim 85 wherein
11 the control system is configured to monitor the temperature of the
12 directed air from the temperature sensor and to control the modifying
13 element responsive to the monitoring of the temperature.

14
15 87. The fuel cell power system according to claim 80 wherein
16 the modifying element comprises a heater.

88. A fuel cell power system comprising:
a housing;
a plurality of terminals;
at least one fuel cell within the housing and electrically coupled
with the terminals and configured to convert chemical energy into
electricity;
a fuel delivery system configured to supply fuel to the at least
one fuel cell;
a fuel sensor positioned within the housing; and
a control system configured to monitor a detection of fuel within
the housing using the fuel detection sensor.

89. The fuel cell power system according to claim 88 wherein
the control system comprises a plurality of distributed controllers.

90. The fuel cell power system according to claim 88 wherein
the at least one fuel cell comprises a plurality of polymer electrolyte
membrane fuel cells.

91. The fuel cell power system according to claim 88 wherein
the at least one fuel cell comprises a plurality of fuel cells.

1 92. The fuel cell power system according to claim 91 wherein
2 the fuel cells are configured to be individually selectively deactivated
3 and remaining ones of the fuel cells are configured to provide electricity
4 to the terminals with others of the fuel cells deactivated.

5
6 93. The fuel cell power system according to claim 88 further
7 comprising an operator interface and the control system is configured
8 to control the operator interface to indicate a detection of fuel.

9
10 94. The fuel cell power system according to claim 88 wherein
11 the fuel sensor comprises a hydrogen gas sensor.

12
13 95. The fuel cell power system according to claim 88 wherein
14 the at least one fuel cell comprises a plurality of fuel cells, and the
15 fuel delivery system comprises a plurality of valves configured supply
16 fuel to respective ones of the fuel cells.

17
18 96. The fuel cell power system according to claim 95 wherein
19 the control system is configured to selectively close the valves responsive
20 to a detection of fuel using the fuel sensor.

21
22 97. The fuel cell power system according to claim 88 further
23 comprising a heater configured to selectively impart heat flux to the
24 fuel sensor.

98. A fuel cell power system comprising:
a housing;
a plurality of terminals;
at least one fuel cell within the housing and electrically coupled
with the terminals and configured to convert chemical energy into
electricity;
a temperature sensor within the housing; and
a control system coupled with the temperature sensor and
configured to monitor the temperature in the housing using the
temperature sensor.

99. The fuel cell power system according to claim 98 wherein
the control system comprises a plurality of distributed controllers.

100. The fuel cell power system according to claim 98 wherein
the at least one fuel cell comprises a plurality of polymer electrolyte
membrane fuel cells.

101. The fuel cell power system according to claim 98 wherein
the at least one fuel cell comprises a plurality of fuel cells.

102. The fuel cell power system according to claim 101 wherein the fuel cells are configured to be individually selectively deactivated and remaining ones of the fuel cells are configured to provide electricity to the terminals with others of the fuel cells deactivated.

103. The fuel cell power system according to claim 98 further comprising an air temperature control assembly configured to at least one of increase and decrease the temperature in the housing.

104. The fuel cell power system according to claim 103 wherein the control system is configured to control the air temperature control assembly.

105. The fuel cell power system according to claim 103 wherein the control system is configured to control the air temperature control assembly to maintain the temperature in the housing within a predefined range.

106. The fuel cell power system according to claim 103 wherein the control system is configured to control the air temperature control assembly to maintain the temperature in the housing within a predefined range of approximately 25 °Celsius to 80 °Celsius.

107. The fuel cell power system according to claim 103 wherein the air temperature control assembly comprises:

a fan configured to circulate air within the housing; and
an air flow device configured to permit selective passage of air at least one of into and out of the housing.

108. The fuel cell power system according to claim 107 wherein the control system is configured to control the fan and the air flow device.

109. The fuel cell power system according to claim 98 further comprising a temperature sensor configured to monitor a temperature exterior of the housing.

110. A fuel cell power system comprising:
a plurality of terminals;
at least one fuel cell within the housing and electrically coupled with the terminals and configured to convert chemical energy into electricity;

at least one switching device configured to selectively shunt the at least one fuel cell; and

a control system configured to control the at least one switching device.

117. The fuel cell power system according to claim 116 wherein the control system is configured to sequentially shunt the fuel cells using the respective switching devices.

118. The fuel cell power system according to claim 116 wherein the control system is configured to shunt individual ones of the fuel cells using the respective switching devices.

119. The fuel cell power system according to claim 116 wherein the control system is configured to shunt the individual ones of the fuel cells according to a specified order.

120. The fuel cell power system according to claim 116 further comprising a plurality of valves individually configured to selectively supply fuel to respective fuel cells, and wherein the control system is configured to control the valves.

121. The fuel cell power system according to claim 120 wherein the control system is configured to cease supply of fuel to shunted fuel cells using respective ones of the valves.

122. The fuel cell power system according to claim 116 wherein the switching devices comprise MOSFET switching devices.

123. A fuel cell power system comprising:
a housing;
a plurality of terminals;
at least one fuel cell within the housing and electrically coupled
with the terminals and configured to convert chemical energy into
electricity;
a switching device coupled intermediate the at least one fuel cell
and one of the terminals; and
a control system coupled with the switching device and configured
to control the switching device to selectively couple the terminal with
the at least one fuel cell.

124. The fuel cell power system according to claim 123 wherein
the control system comprises a plurality of distributed controllers.

125. The fuel cell power system according to claim 123 wherein
the at least one fuel cell comprises a plurality of polymer electrolyte
membrane fuel cells.

126. The fuel cell power system according to claim 123 wherein
the at least one fuel cell comprises a plurality of fuel cells.

127. The fuel cell power system according to claim 126 wherein the fuel cells are configured to be individually selectively deactivated and remaining ones of the fuel cells are configured to provide electricity to the terminals with others of the fuel cells deactivated.

128. The fuel cell power system according to claim 123 wherein the switching device comprises at least one MOSFET switching device.

129. The fuel cell power system according to claim 123 further comprising a temperature sensor positioned within the housing, and the control system is configured to monitor the temperature within the housing and to couple the terminal with the at least one fuel cell using the switching device responsive to the temperature being within a predefined range.

130. A method of controlling a fuel cell power system comprising:
providing a plurality of fuel cells individually configured to convert chemical energy into electricity;
electrically coupling the plurality of fuel cells;
providing a first terminal coupled with the fuel cells;
providing a second terminal coupled with the fuel cells; and
coupling a digital control system with the fuel cells to at least one of monitor and control an operation of the fuel cells.

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131. The method according to claim 130 further comprising monitoring the operation of the fuel cells.

132. The method according to claim 130 further comprising controlling the operation of the fuel cells.

133. The method according to claim 130 wherein the coupling the control system comprises coupling a plurality of distributed controllers.

134. The method according to claim 130 wherein the providing the fuel cells comprises providing polymer electrolyte membrane fuel cells.

135. The method according to claim 134 further comprising deactivating at least one of the fuel cells.

136. The method according to claim 135 wherein the deactivating comprises physically removing.

137. The method according to claim 135 wherein the deactivating comprises electrically bypassing.

138. The method according to claim 135 further comprising providing electricity to a load coupled with the terminals with the at least one fuel cell deactivated.

139. The method according to claim 130 further comprising selectively shunting at least one of the fuel cells.

140. The method according to claim 130 further comprising:
monitoring at least one electrical characteristic of the fuel cells;
and

shunting at least one of the fuel cells responsive to the monitoring.

141. The method according to claim 130 further comprising maintaining an air temperature about the fuel cells in a predefined range.

142. The method according to claim 130 further comprising maintaining an air temperature about the fuel cells in a predefined range of approximately 25 °Celsius to 80 °Celsius.

143. The method according to claim 130 further comprising directing air to the fuel cells using a fan.

1 144. The method according to claim 143 further comprising:
 2 monitoring a load coupled with the terminals; and
 3 controlling the fan responsive to the monitoring using the control
 4 system.

5
 6 145. The method according to claim 130 further comprising:
 7 supplying fuel to the fuel cells using a plurality of auxiliary
 8 valves; and
 9 controlling the auxiliary valves using the control system.

10
 11 146. The method according to claim 145 further comprising:
 12 supplying fuel to the auxiliary valves using a main valve; and
 13 controlling the main valve using the control system.

14
 15 147. The method according to claim 130 further comprising:
 16 communicating with a remote device using a communication port;
 17 and
 18 controlling the communicating using the control system.

19
 20 148. The method according to claim 130 further comprising:
 21 switching a connection intermediate one of the terminals and the
 22 fuel cells; and
 23 controlling the switching using the control system.

24

149. The method according to claim 130 further comprising:
monitoring for the presence of fuel within a housing about the
fuel cells; and
implementing a shut down operation responsive to the monitoring
using the control system.

150. The method according to claim 149 wherein the
implementing deactivates one or more of the fuel cells.

151. The method according to claim 149 wherein the
implementing deactivates all of the fuel cells.

152. A method of controlling a fuel cell power system comprising:
providing at least one fuel cell configured to convert chemical
energy into electricity;

providing a first terminal coupled with the at least one fuel cell;
providing a second terminal coupled with the at least one fuel
cell;

supplying fuel to the at least one fuel cell; and
controlling the supplying using a control system.

153. The method according to claim 152 wherein the controlling
comprises controlling using the control system comprising a plurality of
distributed controllers.

154. The method according to claim 152 wherein the providing the at least one fuel cell comprises providing the at least one fuel cell having a plurality of polymer electrolyte membrane fuel cells.

155. The method according to claim 152 wherein the providing the at least one fuel cell comprises providing a plurality of fuel cells.

156. The method according to claim 155 further comprising deactivating at least one of the fuel cells.

157. The method according to claim 156 further comprising providing electricity to a load coupled with the terminals with the at least one fuel cell deactivated.

158. The method according to claim 152 further comprising monitoring at least one electrical characteristic of the at least one fuel cell, and the controlling is responsive to the monitoring.

159. A method of controlling a fuel cell power system comprising:
providing at least one fuel cell configured to convert chemical
energy into electricity;
providing a first terminal coupled with the at least one fuel cell;
providing a second terminal coupled with the at least one fuel
cell;
selectively exhausting a connection coupled with the at least one
fuel cell; and
controlling the exhausting using a control system.

160. The method according to claim 159 wherein the controlling
comprises controlling using the control system comprising a plurality of
distributed controllers.

161. The method according to claim 159 wherein the providing
the at least one fuel cell comprises providing the at least one fuel cell
having a plurality of polymer electrolyte membrane fuel cells.

162. The method according to claim 159 wherein the providing
the at least one fuel cell comprises providing a plurality of fuel cells.

163. The method according to claim 162 further comprising
deactivating at least one of the fuel cells.

164. The method according to claim 163 further comprising providing electricity to a load coupled with the terminals with the at least one fuel cell deactivated.

165. The method according to claim 159 wherein the selectively exhausting comprises periodically exhausting responsive to control of the control system.

166. The method according to claim 159 wherein the exhausting comprises exhausting using a bleed valve.

167. The method according to claim 159 wherein the exhausting comprises exhausting from an anode of the at least one fuel cell.

168. A method of controlling a fuel cell power system comprising: providing at least one fuel cell configured to convert chemical energy into electricity;

providing a first terminal coupled with the at least one fuel cell; providing a second terminal coupled with the at least one fuel cell;

directing air to the at least one fuel cell; and controlling the directing using a control system.

169. The method according to claim 168 wherein the controlling comprises controlling using the control system comprising a plurality of distributed controllers.

170. The method according to claim 168 wherein the providing the at least one fuel cell comprises providing the at least one fuel cell having a plurality of polymer electrolyte membrane fuel cells.

171. The method according to claim 168 wherein the providing the at least one fuel cell comprises providing a plurality of fuel cells.

172. The method according to claim 171 further comprising deactivating at least one of the fuel cells.

173. The method according to claim 172 further comprising providing electricity to a load coupled with the terminals with the at least one fuel cell deactivated.

174. The method according to claim 168 further comprising providing electricity to a load coupled with the terminals, and the controlling is responsive to the monitoring.

175. The method according to claim 168 further comprising monitoring at least one of voltage of the at least one fuel cell and current passing through the at least one fuel cell, and the controlling is responsive to the monitoring.

176. The method according to claim 168 wherein the directing comprises directing air into a cathode side of the at least on fuel cell.

177. The method according to claim 176 wherein the directing comprises directing using a fan, and the controlling comprises controlling an air flow rate of the fan.

178. The method according to claim 168 further comprising introducing exterior air into a housing about the at least one fuel cell.

179. The method according to claim 168 further comprising monitoring the temperature of the air.

180. The method according to claim 179 further comprising controlling a modifying element using the control system to control the temperature of the air responsive to the monitoring.

181. A method of controlling a fuel cell power system comprising:
providing at least one fuel cell configured to convert chemical
energy into electricity;
providing a first terminal coupled with the at least one fuel cell;
providing a second terminal coupled with the at least one fuel
cell;
indicating at least one operational status of the fuel cell power
system using an operator interface; and
controlling the indicating using a control system.

182. The method according to claim 181 wherein the controlling
comprises controlling using the control system comprising a plurality of
distributed controllers.

183. The method according to claim 181 wherein the providing
the at least one fuel cell comprises providing the at least one fuel cell
having a plurality of polymer electrolyte membrane fuel cells.

184. The method according to claim 181 wherein the providing
the at least one fuel cell comprises providing a plurality of fuel cells.

185. The method according to claim 184 further comprising
deactivating at least one of the fuel cells.

186. The method according to claim 185 further comprising providing electricity to a load coupled with the terminals with the at least one fuel cell deactivated.

187. The method according to claim 181 wherein the indicating comprises emitting a human perceptible signal.

188. The method according to claim 181 wherein the indicating comprises indicating using a display.

189. The method according to claim 181 further comprising forwarding the at least one operational status to a remote device.

190. The method according to claim 181 further comprising receiving operator inputs using the operator interface.

1 191. A method of controlling a fuel cell power system comprising:
2 providing at least one fuel cell configured to convert chemical
3 energy into electricity;
4 providing a first terminal coupled with the at least one fuel cell;
5 providing a second terminal coupled with the at least one fuel
6 cell;
7 supplying electricity using a power supply; and
8 monitoring at least one electrical condition of the power supply
9 using a control system.
10

11 192. The method according to claim 191 wherein the controlling
12 comprises controlling using the control system comprising a plurality of
13 distributed controllers.
14

15 193. The method according to claim 191 wherein the providing
16 the at least one fuel cell comprises providing the fuel cell having a
17 plurality of polymer electrolyte membrane fuel cells.
18

19 194. The method according to claim 191 wherein the providing
20 the at least one fuel cell comprises providing a plurality of fuel cells.
21

22 195. The method according to claim 194 further comprising
23 deactivating at least one of the fuel cells.
24

196. The method according to claim 195 further comprising providing electricity to a load coupled with the terminals with the at least one fuel cell deactivated.

197. The method according to claim 191 wherein the supplying comprises supplying electricity to the control system.

198. The method according to claim 191 wherein the supplying comprises supplying power using the power supply comprising a battery.

199. The method according to claim 198 further comprising:
charging the battery; and
controlling the charging using the control system.

200. A method of controlling a fuel cell power system comprising:
providing at least one fuel cell configured to convert chemical energy into electricity;

providing a first terminal coupled with the at least one fuel cell;
providing a second terminal coupled with the at least one fuel cell; and

monitoring an electrical condition of the at least one fuel cell using a control system.

1 201. The method according to claim 200 wherein the controlling
2 comprises controlling using the control system comprising a plurality of
3 distributed controllers.

4
5 202. The method according to claim 200 wherein the providing
6 the at least one fuel cell comprises providing the fuel cell having a
7 plurality of polymer electrolyte membrane fuel cells.

8
9 203. The method according to claim 200 wherein the providing
10 the at least one fuel cell comprises providing a plurality of fuel cells.

11
12 204. The method according to claim 203 further comprising
13 deactivating at least one of the fuel cells.

14
15 205. The method according to claim 204 further comprising
16 providing electricity to a load coupled with the terminals with the at
17 least one fuel cell deactivated.

18
19 206. The method according to claim 200 further comprising
20 indicating the electrical condition using an operator interface.

1 207. The method according to claim 200 further comprising:
2 directing air to the at least one fuel cell; and
3 controlling the directing using the control system responsive to the
4 monitoring.

5
6 208. The method according to claim 200 further comprising
7 shunting the at least one fuel cell after the monitoring.

8
9 209. A method of controlling a fuel cell power system comprising:
10 providing a plurality of fuel cells individually configured to convert
11 chemical energy into electricity;
12 providing a first terminal coupled with the fuel cells;
13 providing a second terminal coupled with the fuel cells;
14 supplying fuel to the fuel cells; and
15 controlling the supplying using a control system.

16
17 210. The method according to claim 209 wherein the controlling
18 comprises controlling using the control system comprising a plurality of
19 distributed controllers.

20
21 211. The method according to claim 209 wherein the providing
22 the fuel cells comprises providing a plurality of polymer electrolyte
23 membrane fuel cells.
24

1 212. The method according to claim 209 further comprising
2 deactivating at least one of the fuel cells.

3
4 213. The method according to claim 212 further comprising
5 providing electricity to a load coupled with the terminals with the at
6 least one fuel cell deactivated.

7
8 214. The method according to claim 209 wherein the supplying
9 comprises supplying using a main valve.

10
11 215. The method according to claim 209 wherein the supplying
12 comprises:

13 supplying using a main valve; and

14 supplying using a plurality of auxiliary valves.

15
16 216. The method according to claim 215 wherein the controlling
17 comprises controlling the main valve and the auxiliary valves using the
18 control system.

1 217. A method of controlling a fuel cell power system comprising:
2 providing at least one fuel cell configured to convert chemical
3 energy into electricity;
4 providing a first terminal coupled with the at least one fuel cell;
5 providing a second terminal coupled with the at least one fuel
6 cell;
7 supplying fuel to the at least one fuel cell; and
8 monitoring for the presence of fuel within a housing about the
9 at least one fuel cell using a control system.

10
11 218. The method according to claim 217 wherein the controlling
12 comprises controlling using the control system comprising a plurality of
13 distributed controllers.

14
15 219. The method according to claim 217 wherein the providing
16 the at least one fuel cell comprises providing the fuel cell having a
17 plurality of polymer electrolyte membrane fuel cells.

18
19 220. The method according to claim 217 wherein the providing
20 the at least one fuel cell comprises providing a plurality of fuel cells.

21
22 221. The method according to claim 220 further comprising
23 deactivating at least one of the fuel cells.
24

1 222. The method according to claim 221 further comprising
2 providing electricity to a load coupled with the terminals with the at
3 least one fuel cell deactivated.

4
5 223. The method according to claim 217 further comprising:
6 coupling an operator interface with the control system; and
7 controlling the operator interface using the control system to
8 indicate the presence of fuel within the housing.

9
10 224. The method according to claim 217 further comprising:
11 selectively ceasing the supplying responsive to the monitoring; and
12 controlling the ceasing using the control system.

13
14 225. The method according to claim 217 wherein the monitoring
15 comprises monitoring using a fuel sensor.

16
17 226. The method according to claim 225 further comprising
18 heating the fuel sensor.

227. A method of controlling a fuel cell power system comprising:
providing at least one fuel cell configured to convert chemical
energy into electricity;
providing a first terminal coupled with the at least one fuel cell;
providing a second terminal coupled with the at least one fuel
cell; and
monitoring a temperature within a housing about the at least one
fuel cell using a control system.

228. The method according to claim 227 wherein the controlling
comprises controlling using the control system comprising a plurality of
distributed controllers.

229. The method according to claim 227 wherein the providing
the at least one fuel cell comprises providing the fuel cell having a
plurality of polymer electrolyte membrane fuel cells.

230. The method according to claim 227 wherein the providing
the at least one fuel cell comprises providing a plurality of fuel cells.

231. The method according to claim 230 further comprising
deactivating at least one of the fuel cells.

1 232. The method according to claim 231 further comprising
2 providing electricity to a load coupled with the terminals with the at
3 least one fuel cell deactivated.

4
5 233. The method according to claim 227 further comprising
6 selectively one of increasing and decreasing the temperature in the
7 housing using an air temperature control assembly.

8
9 234. The method according to claim 233 further comprising
10 controlling the air temperature control assembly using the control system
11 and responsive to the monitoring.

12
13 235. The method according to claim 234 wherein the controlling
14 comprises controlling to maintain the temperature in the housing within
15 a predefined range.

16
17 236. The method according to claim 234 wherein the controlling
18 comprises controlling to maintain the temperature in the housing within
19 a predefined range of approximately 25 °Celsius and 80 °Celsius.

20
21 237. The method according to claim 227 further comprising:
22 directing air to the at least one fuel cell; and
23 controlling the directing using the control system and responsive
24 to the monitoring.

1 238. The method according to claim 227 further comprising:
2 inputting exterior air into the housing; and
3 controlling the inputting using the control system and responsive
4 to the monitoring.

5
6 239. The method according to claim 227 further comprising
7 monitoring a temperature exterior of the housing.

8
9 240. The method according to claim 227 wherein the monitoring
10 comprises monitoring using a temperature sensor.

11
12 241. A method of controlling a fuel cell power system comprising:
13 providing at least one fuel cell configured to convert chemical
14 energy into electricity;

15 providing a first terminal coupled with the at least one fuel cell;
16 providing a second terminal coupled with the at least one fuel
17 cell;

18 shunting the at least one fuel cell; and
19 controlling the shunting using a control system.

20
21 242. The method according to claim 241 wherein the controlling
22 comprises controlling using the control system comprising a plurality of
23 distributed controllers.

24

243. The method according to claim 241 wherein the providing the at least one fuel cell comprises providing the fuel cell having a plurality of polymer electrolyte membrane fuel cells.

244. The method according to claim 241 further comprising varying a period of time of the shunting using the control system.

245. The method according to claim 241 wherein the providing the at least one fuel cell comprises providing a plurality of fuel cells.

246. The method according to claim 245 further comprising deactivating at least one of the fuel cells.

247. The method according to claim 246 further comprising providing electricity to a load coupled with the terminals with the at least one fuel cell deactivated.

248. The method according to claim 245 further comprising sequentially shunting the fuel cells.

249. The method according to claim 245 further comprising shunting individual ones of the fuel cells.

1 250. The method according to claim 245 further comprising
2 shunting the fuel cells according to a specified order.

3
4 251. The method according to claim 245 further comprising:
5 supplying fuel to the fuel cells; and
6 ceasing the supplying to shunted fuel cells.

7
8 252. A method of controlling a fuel cell power system comprising:
9 providing at least one fuel cell configured to convert chemical
10 energy into electricity;
11 providing a first terminal coupled with the at least one fuel cell;
12 providing a second terminal coupled with the at least one fuel
13 cell;
14 switching a connection immediate one of the terminals and the at
15 least one fuel cell; and
16 controlling the switching using a control system.

17
18 253. The method according to claim 252 wherein the controlling
19 comprises controlling using the control system comprising a plurality of
20 distributed controllers.

21
22 254. The method according to claim 252 wherein the providing
23 the at least one fuel cell comprises providing the fuel cell having a
24 plurality of polymer electrolyte membrane fuel cells.

1 255. The method according to claim 252 wherein the providing
2 the at least one fuel cell comprises providing a plurality of fuel cells.
3

4 256. The method according to claim 255 further comprising
5 deactivating at least one of the fuel cells.
6

7 257. The method according to claim 256 further comprising
8 providing electricity to a load coupled with the terminals with the at
9 least one fuel cell deactivated.
10

11 258. The method according to claim 252 further comprising
12 monitoring a temperature within a housing about the at least one fuel
13 cell and the controlling is responsive to the monitoring.
14

15 259. A method of operating a fuel cell power system comprising:
16 initiating a start-up procedure;

17 monitoring the temperature within a housing containing at least
18 one fuel cell;

19 selectively adjusting the temperature within the housing using a
20 modifying element responsive to the monitoring; and

21 coupling a power bus with a terminal responsive to the
22 monitoring.
23
24

1 260. The method according to claim 259 further comprising
2 monitoring for the presence of fuel.

3
4 261. The method according to claim 259 further comprising:
5 shunting the at least one fuel cell according to a duty cycle; and
6 selectively setting the duty cycle to maximum.

7
8 262. The method according to claim 259 wherein the adjusting
9 comprises heating using the modifying element to increase the
10 temperature.

11

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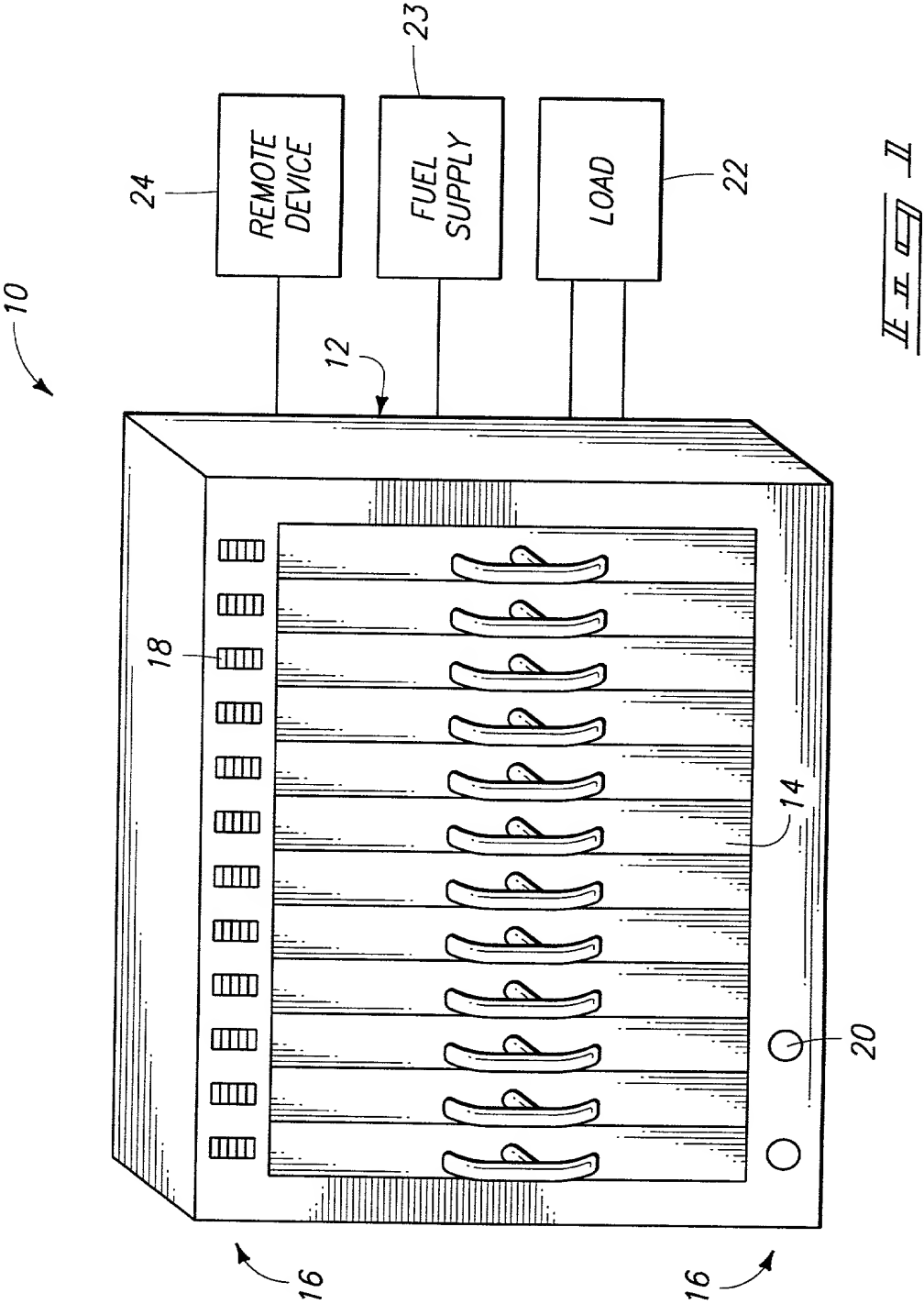
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1 ABSTRACT OF THE DISCLOSURE

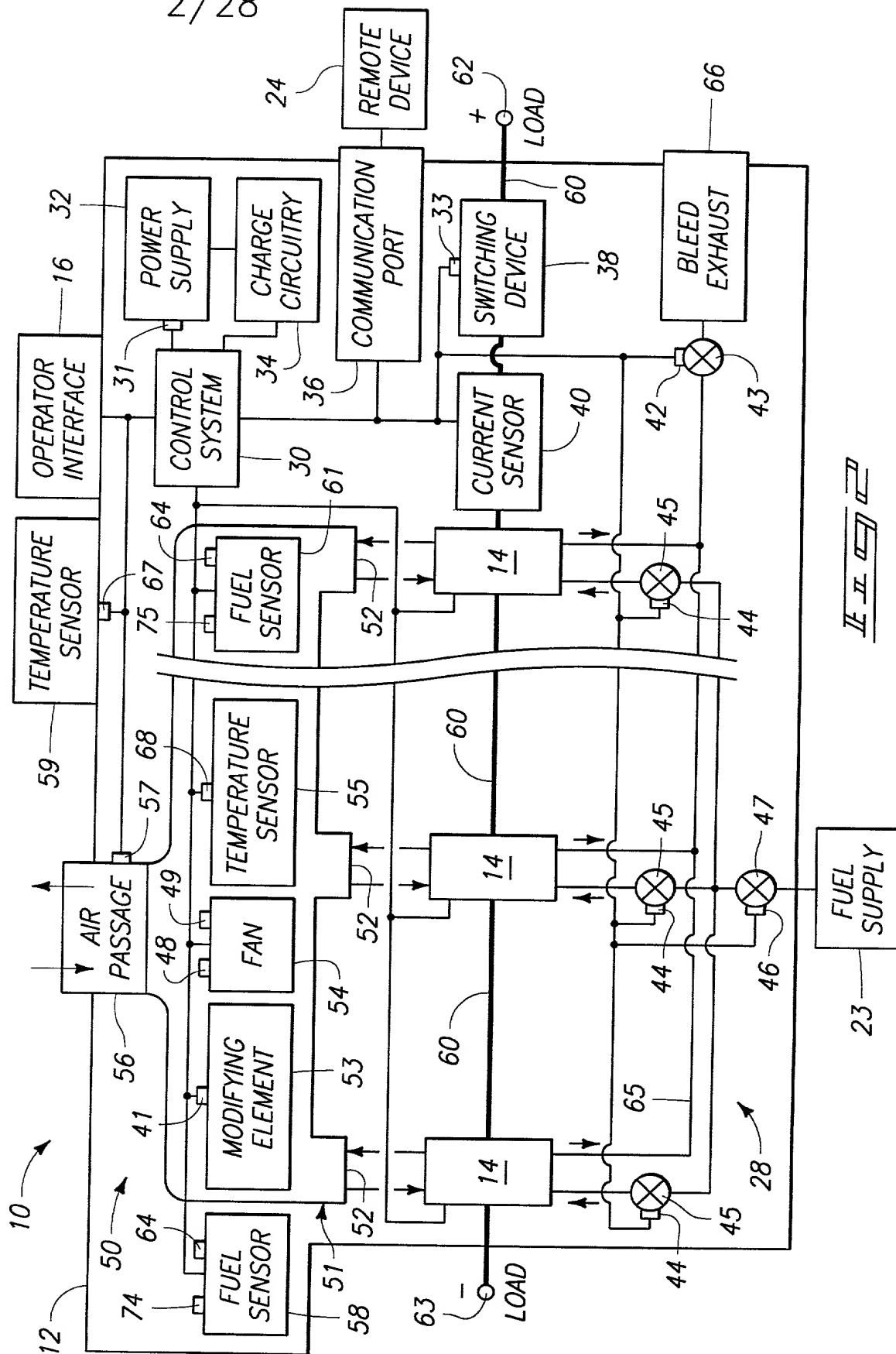
2 Fuel cell power systems and methods of controlling a fuel cell
3 power system are provided. According to one aspect, a fuel cell power
4 system includes a plurality of fuel cells electrically coupled with plural
5 terminals and individually configured to convert chemical energy into
6 electricity; and a digital control system configured to at least one of
7 control and monitor an operation of the fuel cells. Another aspect
8 provides a method of controlling a fuel cell power system including
9 providing a plurality of fuel cells individually configured to convert
10 chemical energy into electricity; electrically coupling the plurality of fuel
11 cells; providing a first terminal coupled with the fuel cells; providing a
12 second terminal coupled with the fuel cells; and coupling a digital
13 control system with the fuel cells to at least one of monitor and
14 control an operation of the fuel cells.
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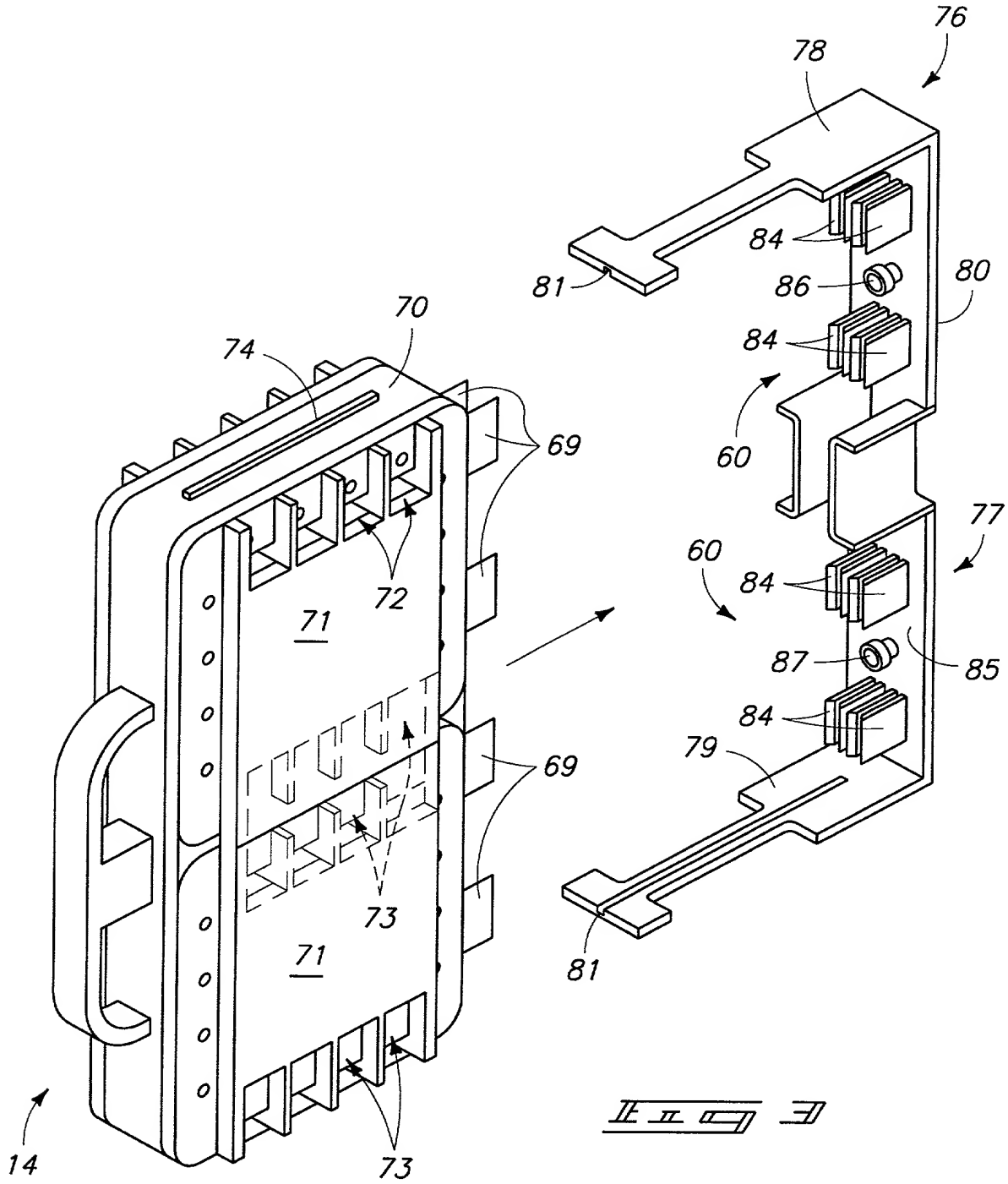


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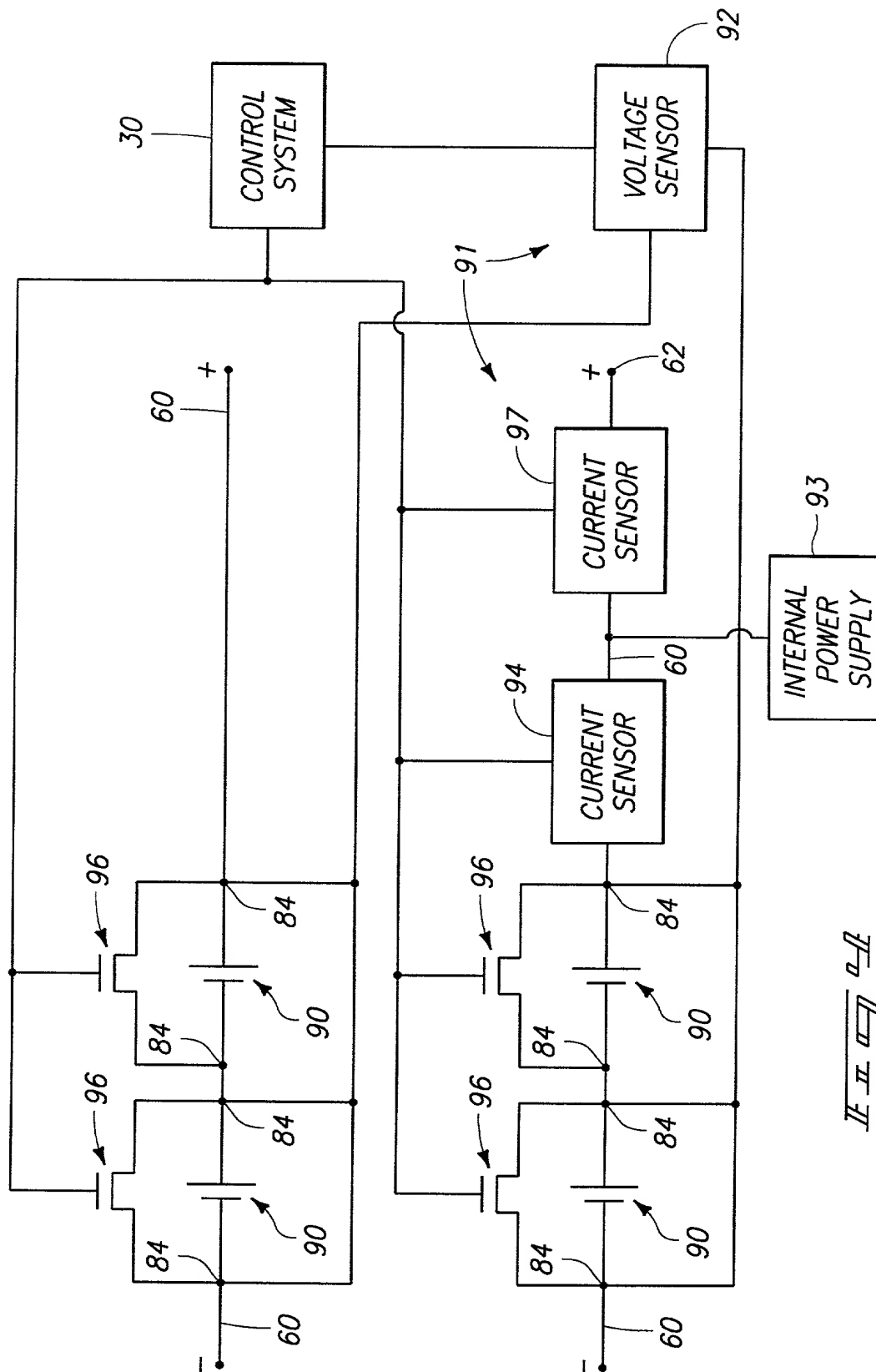


FIG. 4

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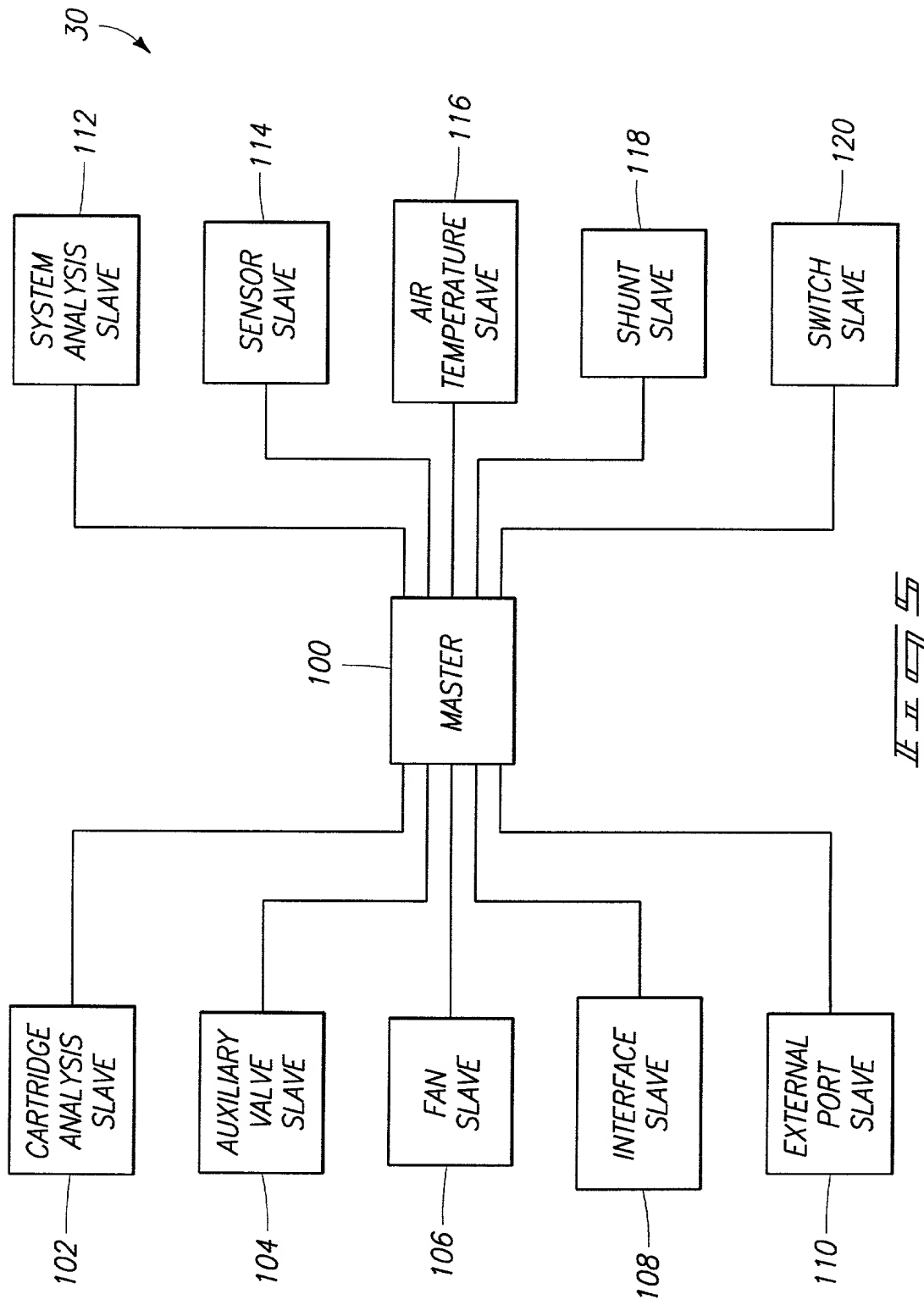
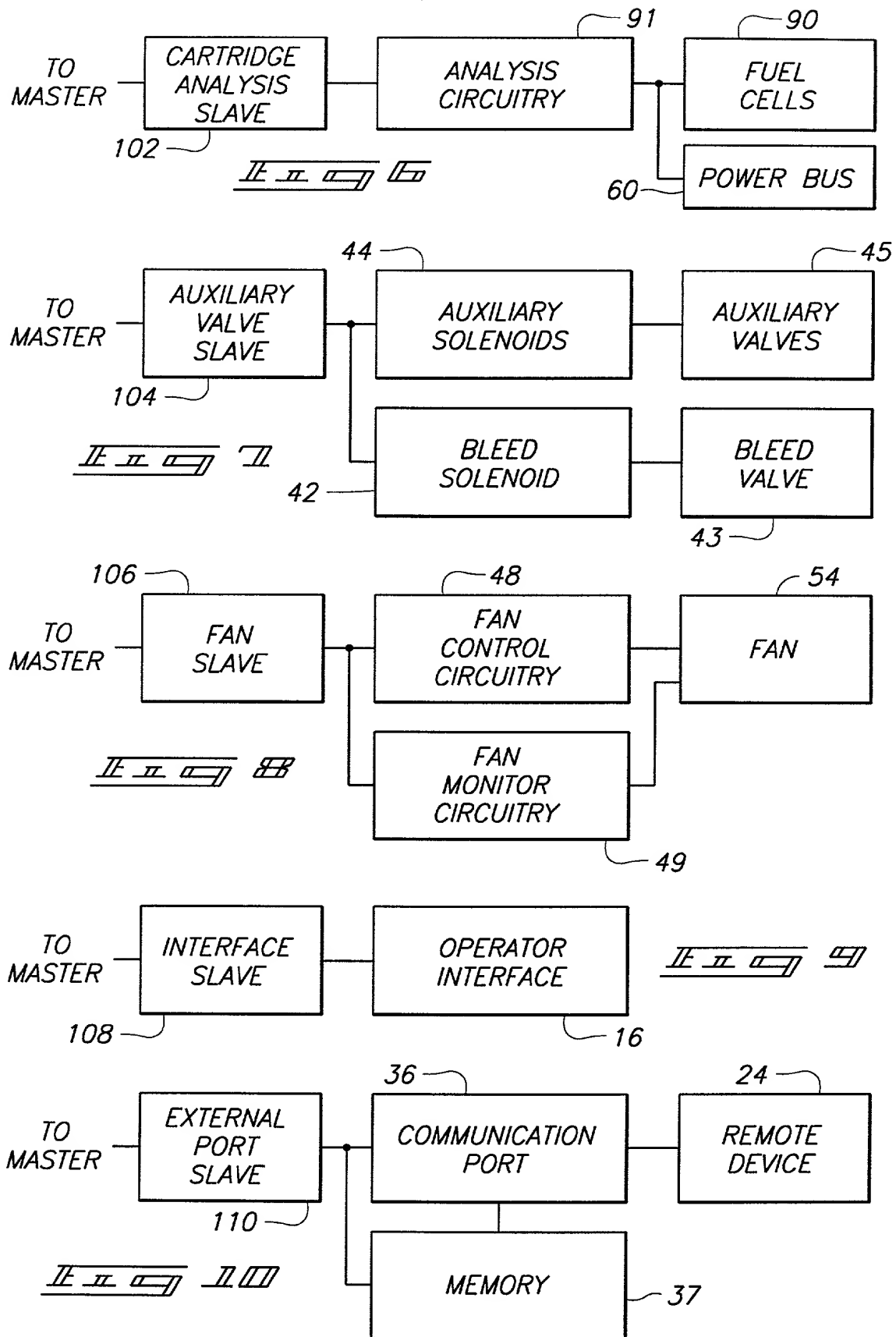
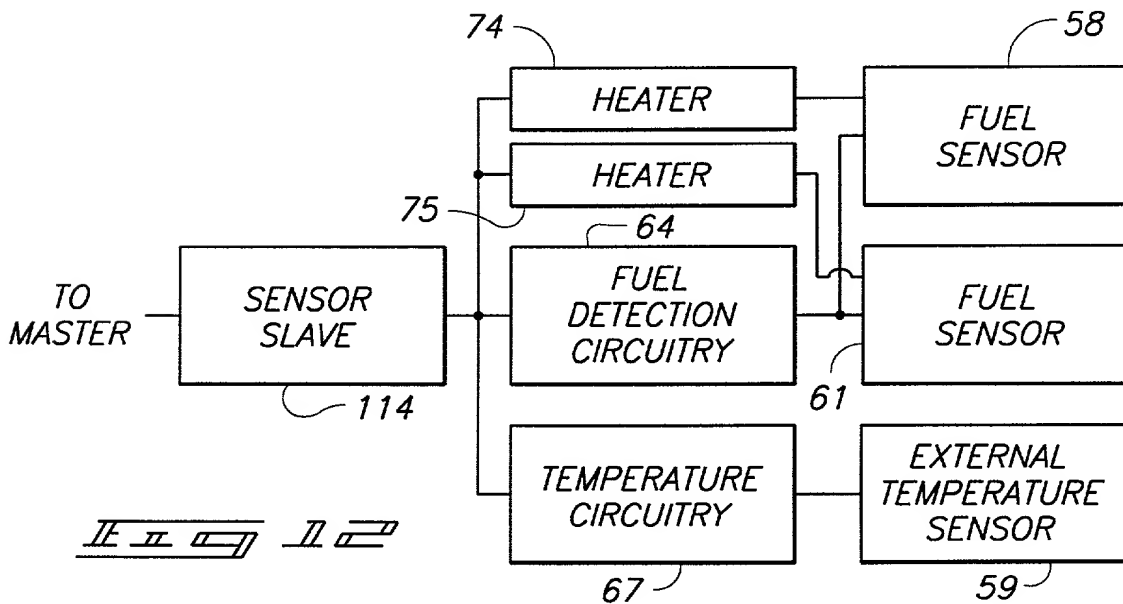
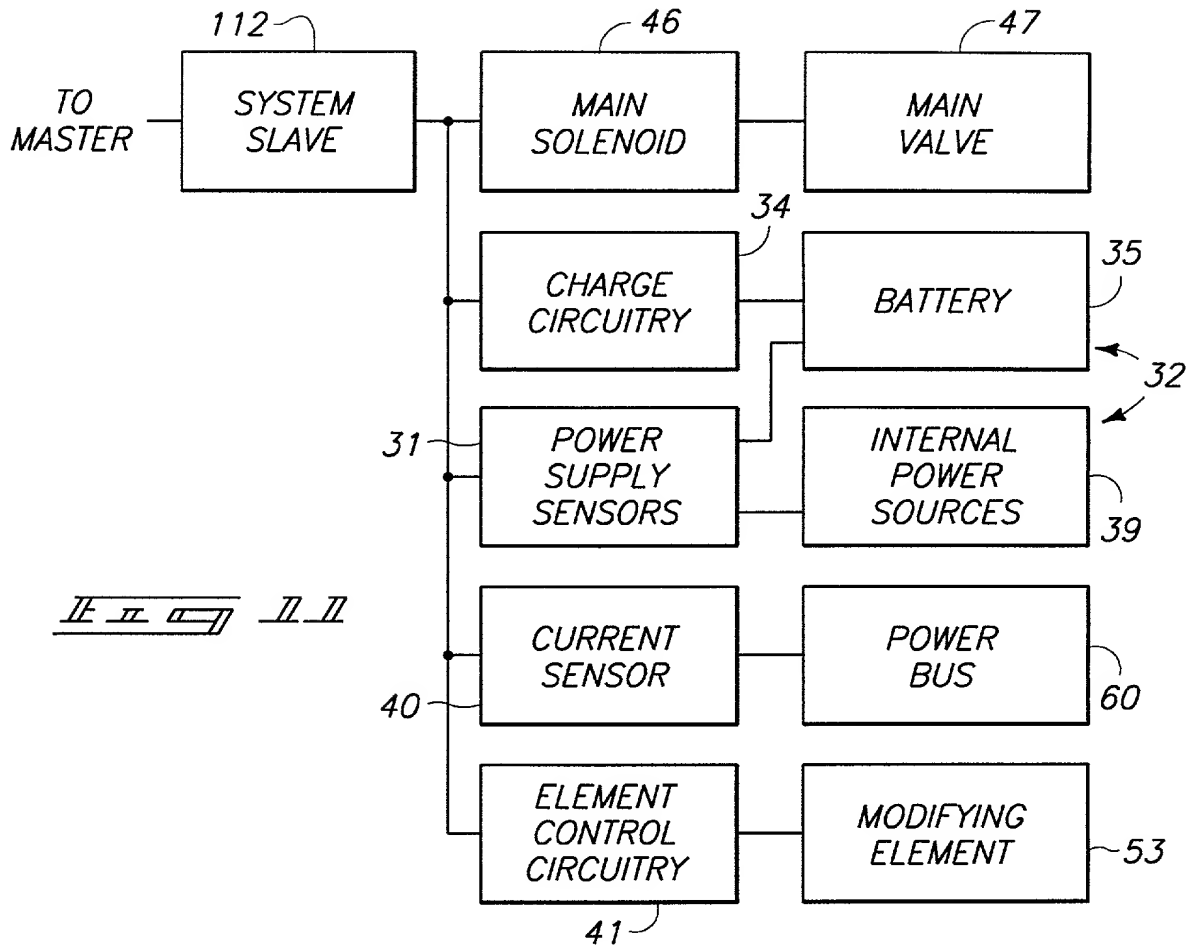


FIG. 5

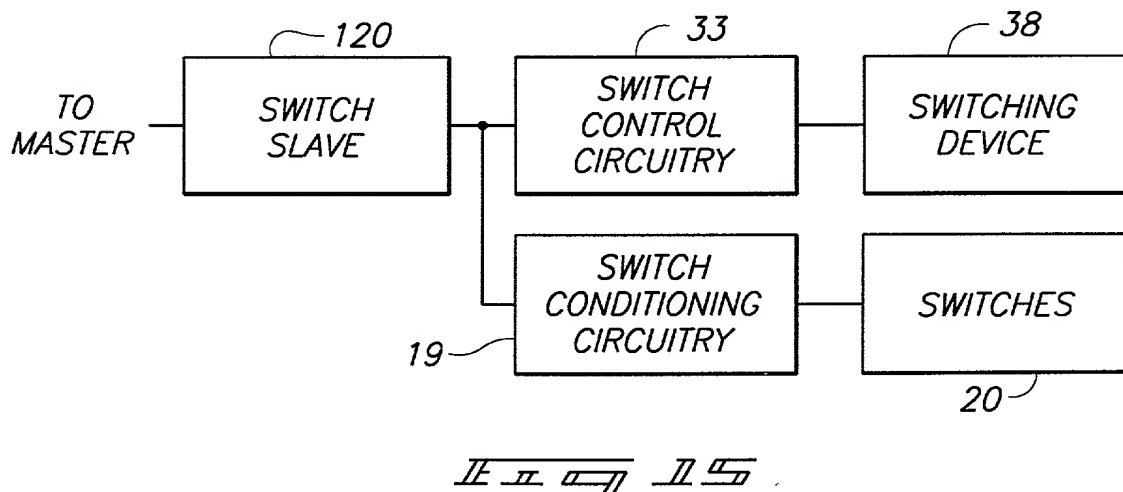
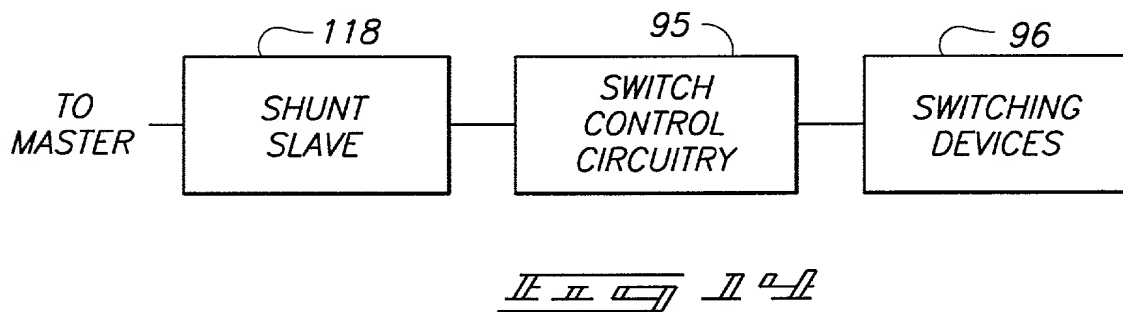
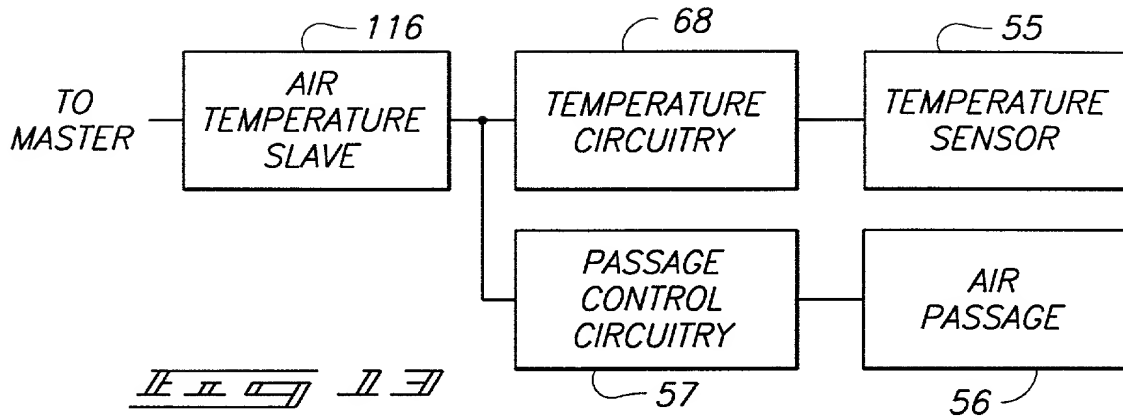
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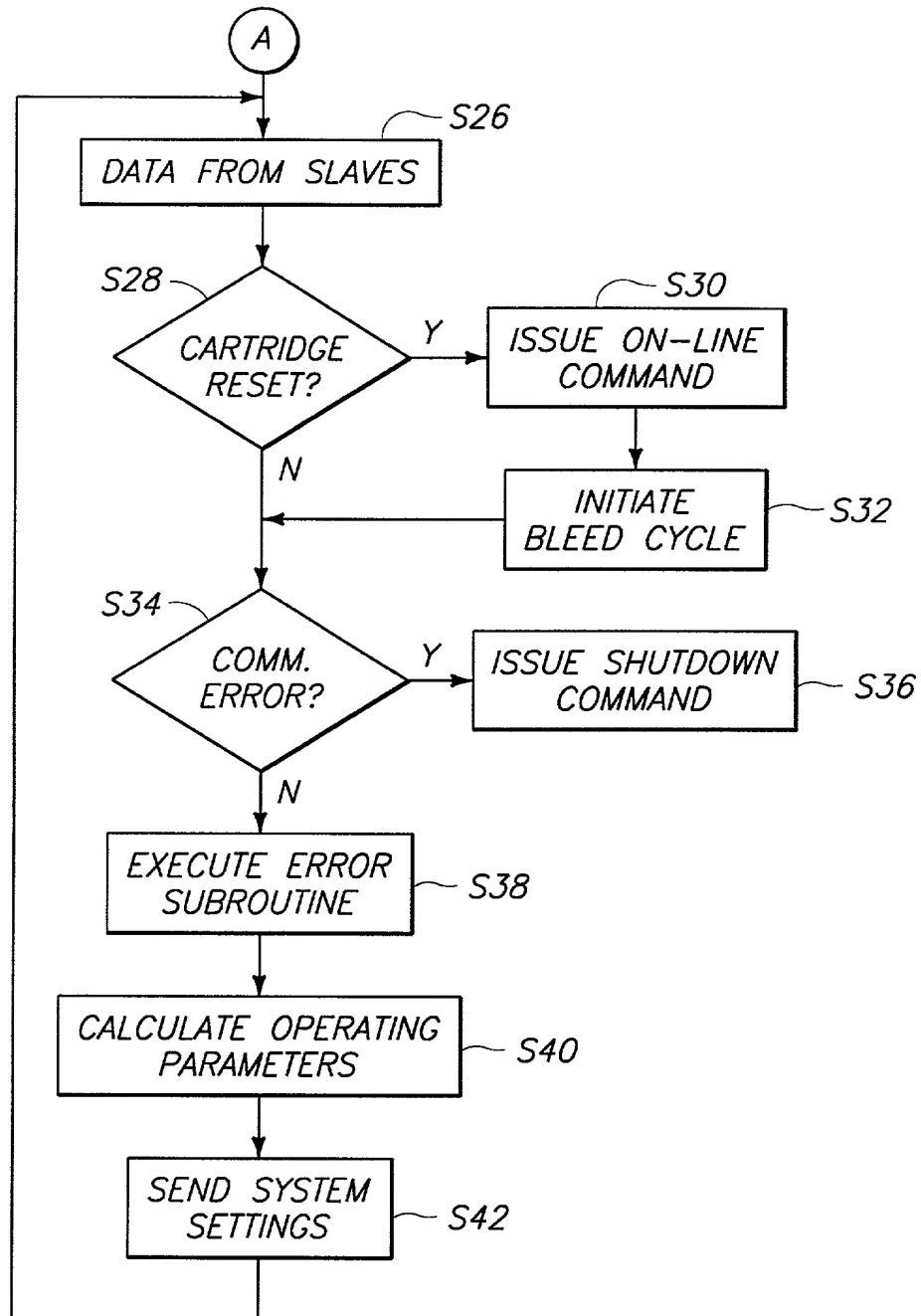
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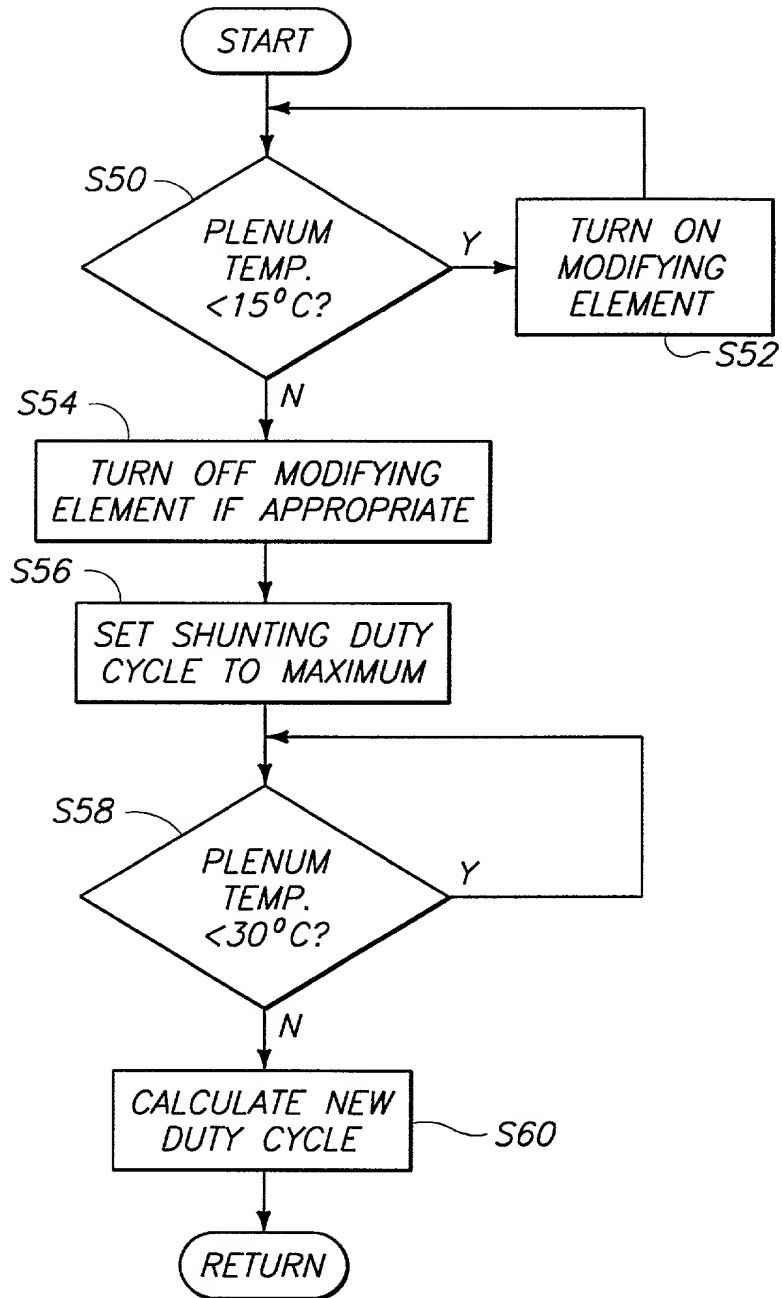
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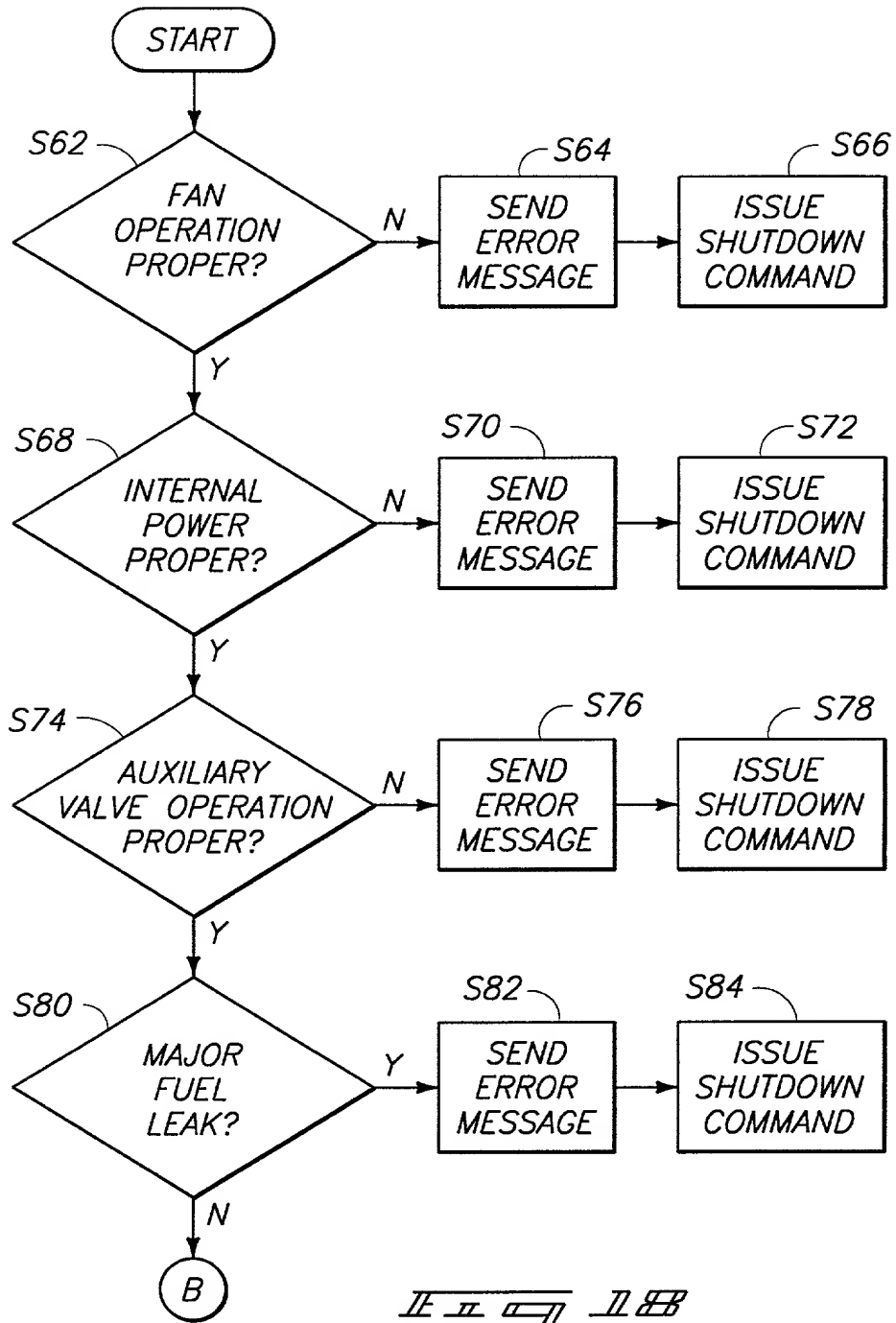
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FIG. 10

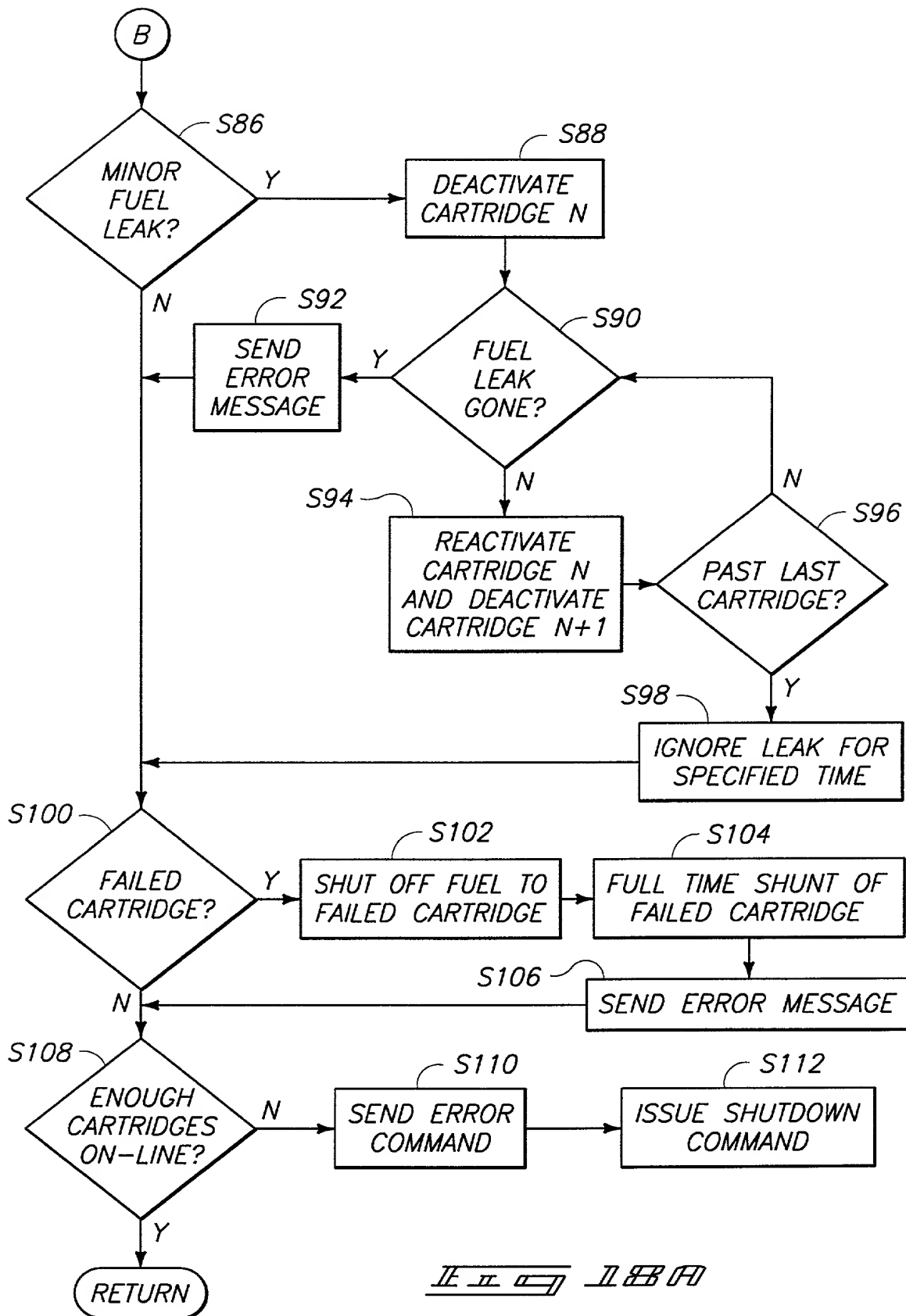
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FIG. 11

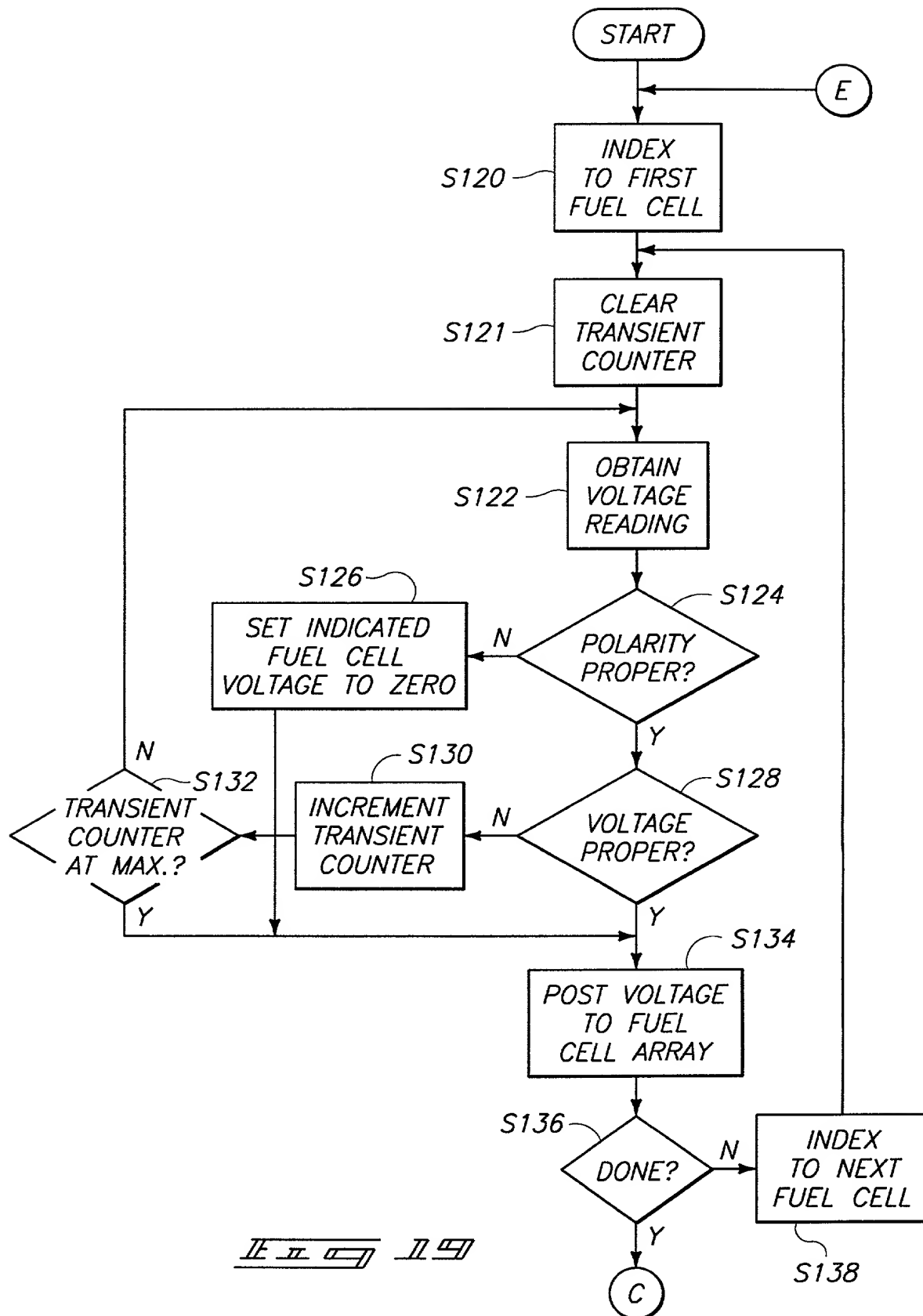
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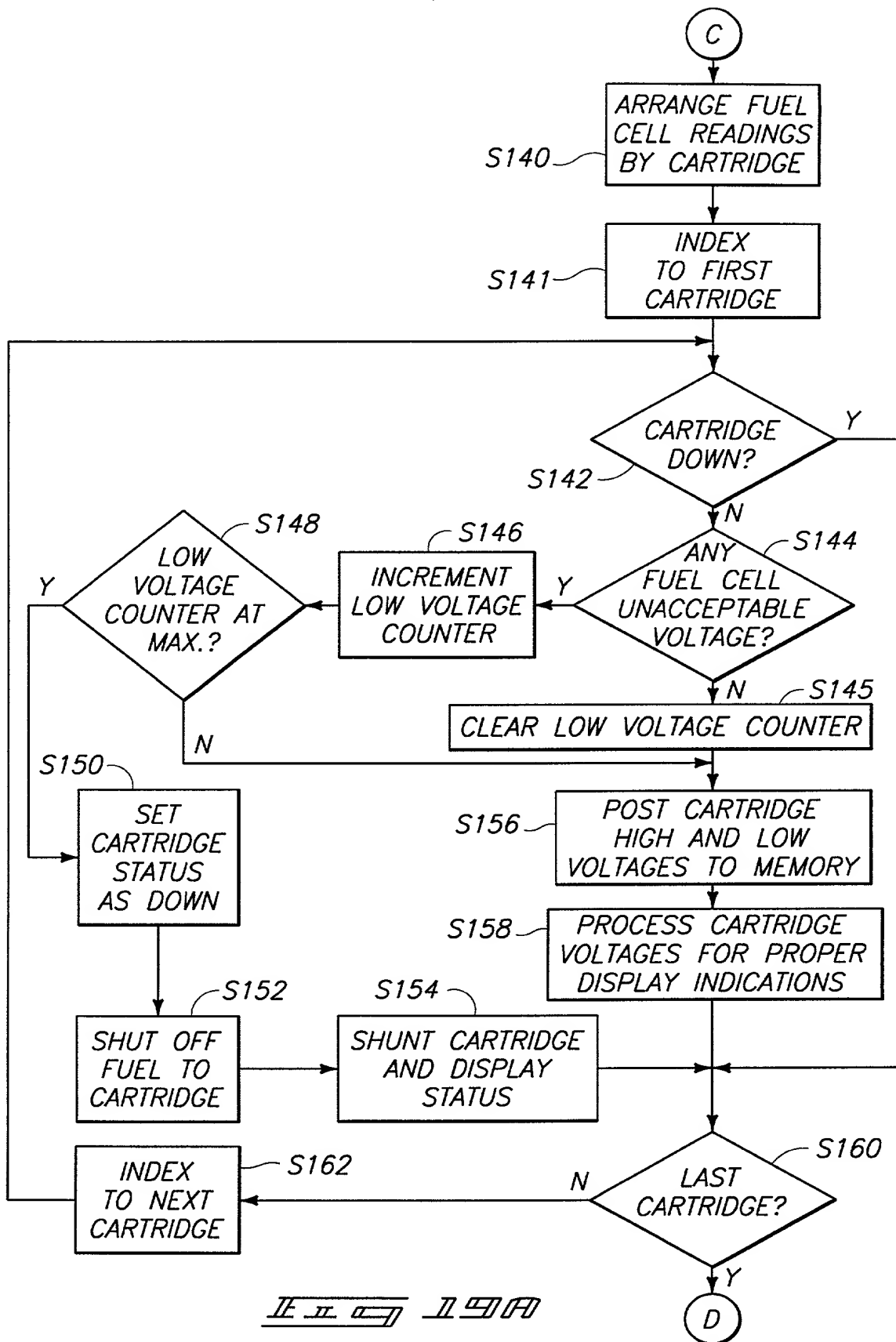
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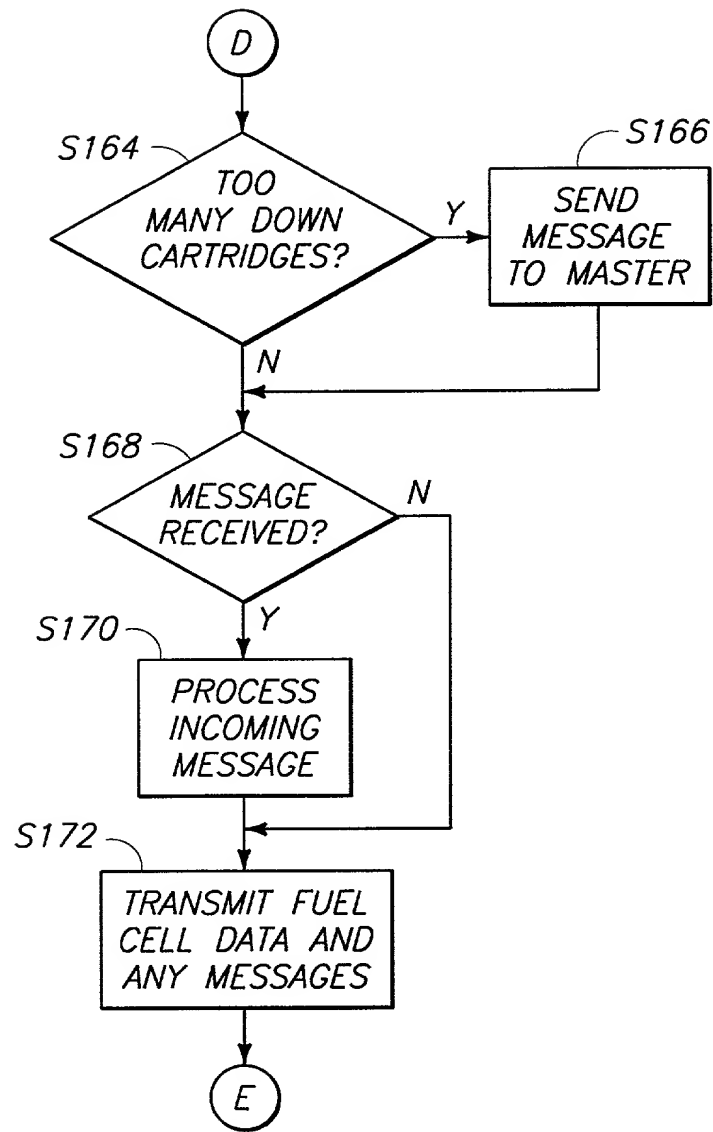
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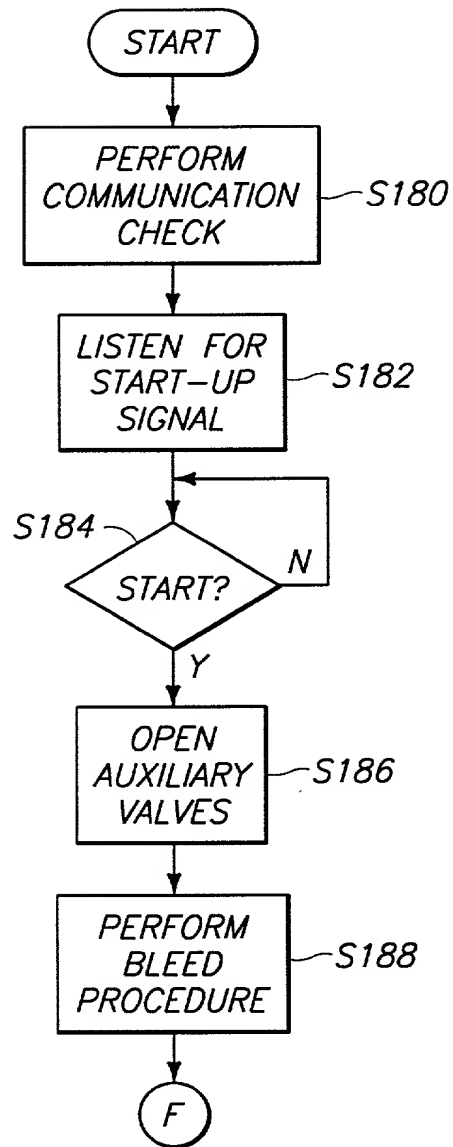
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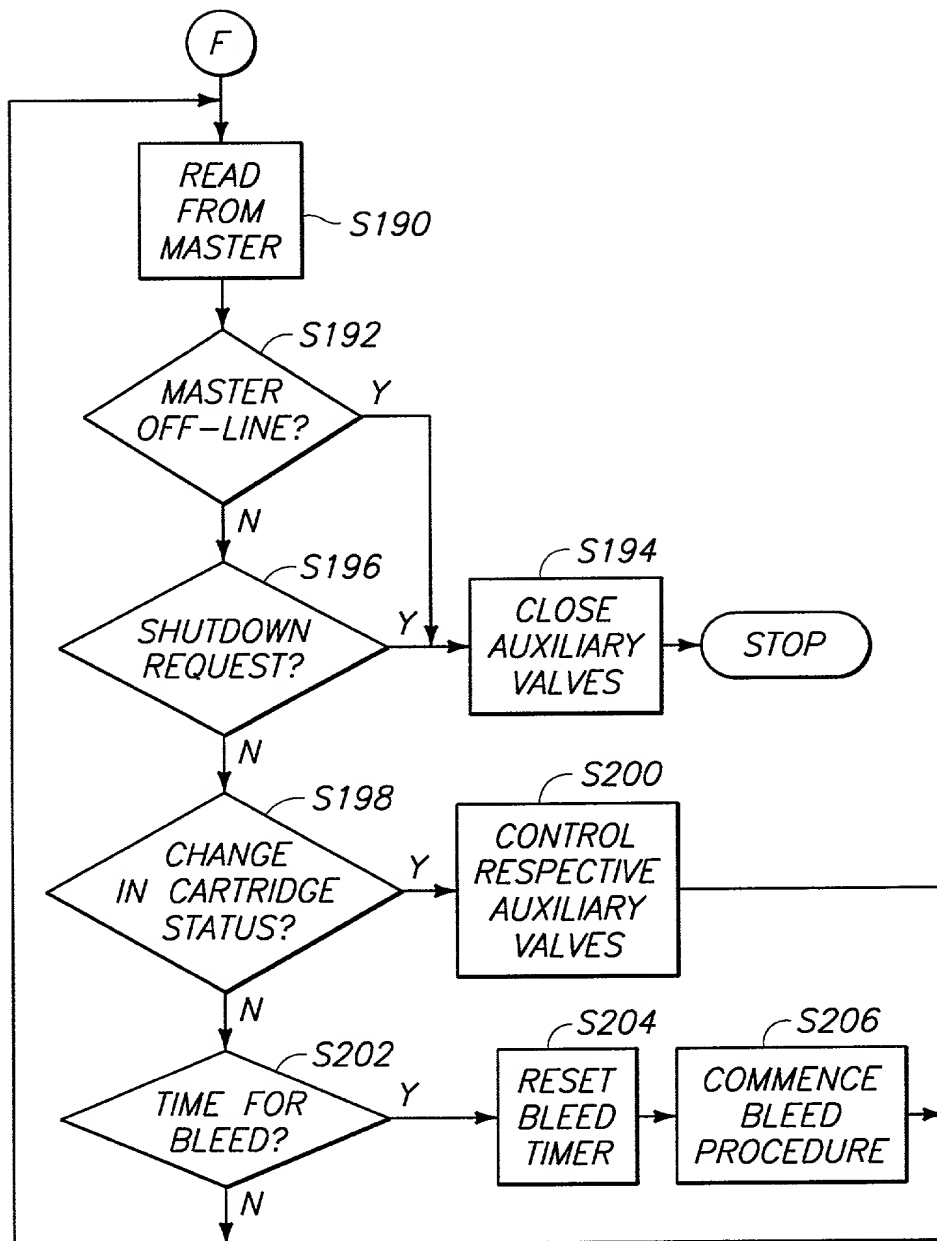
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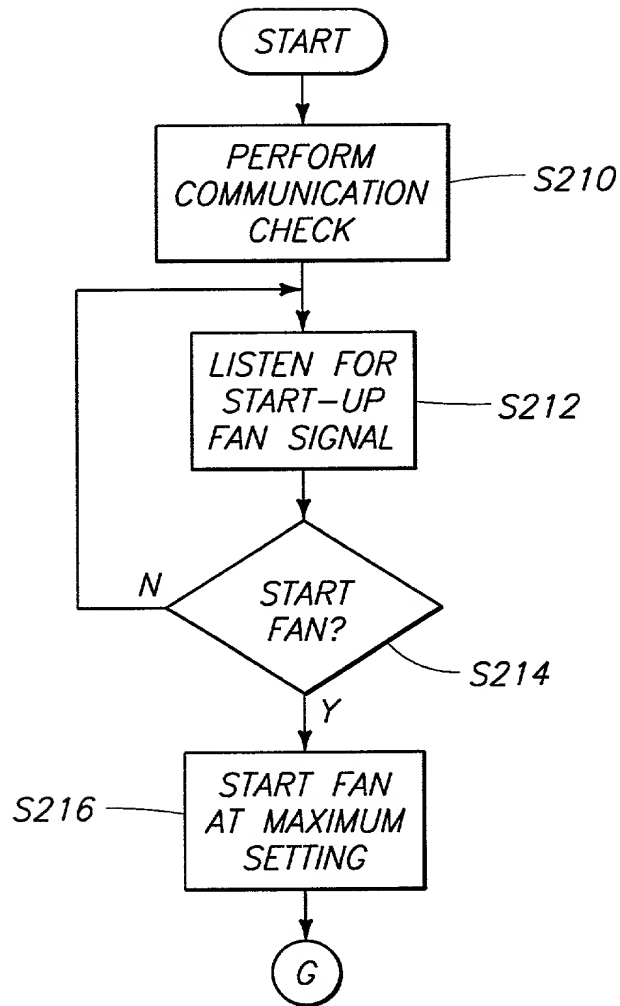
FIG. 20

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FIG. 19

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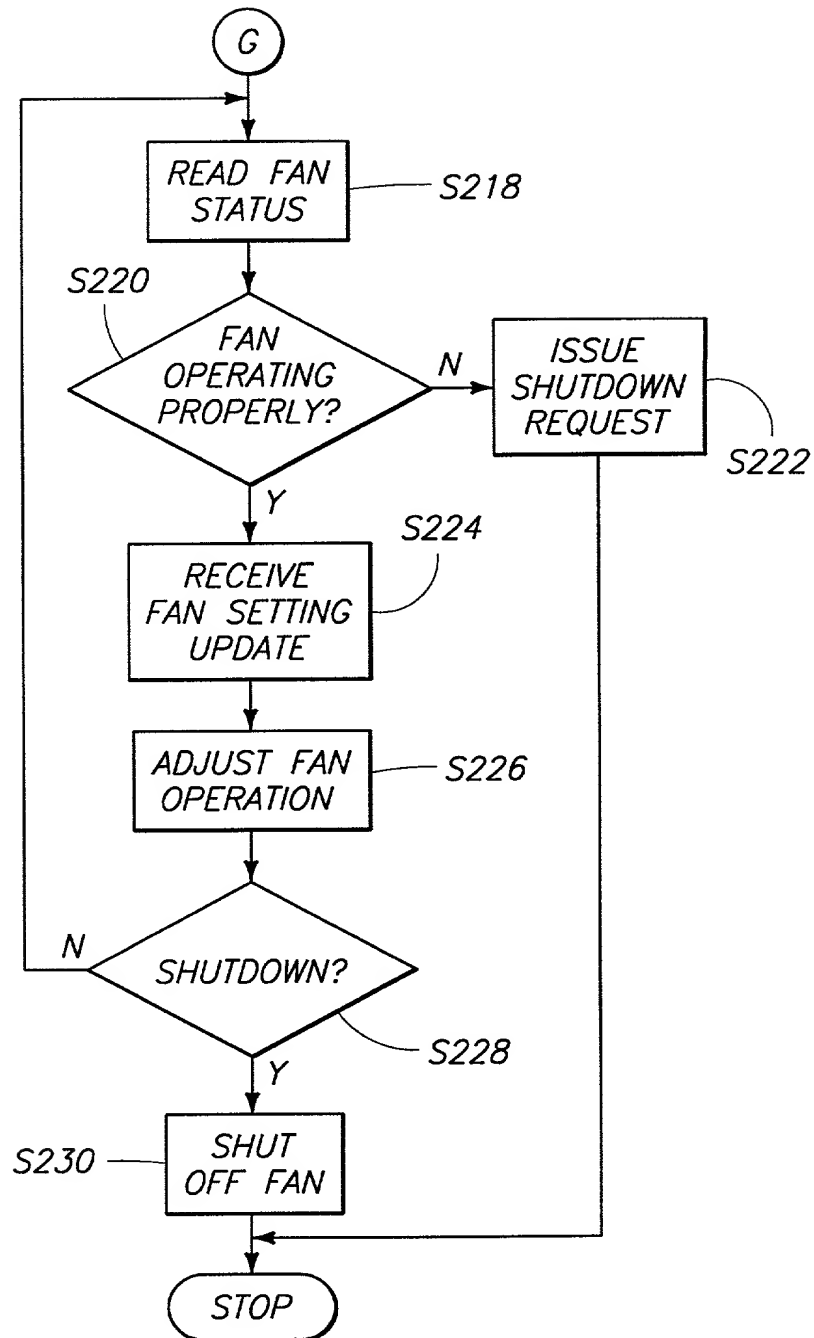
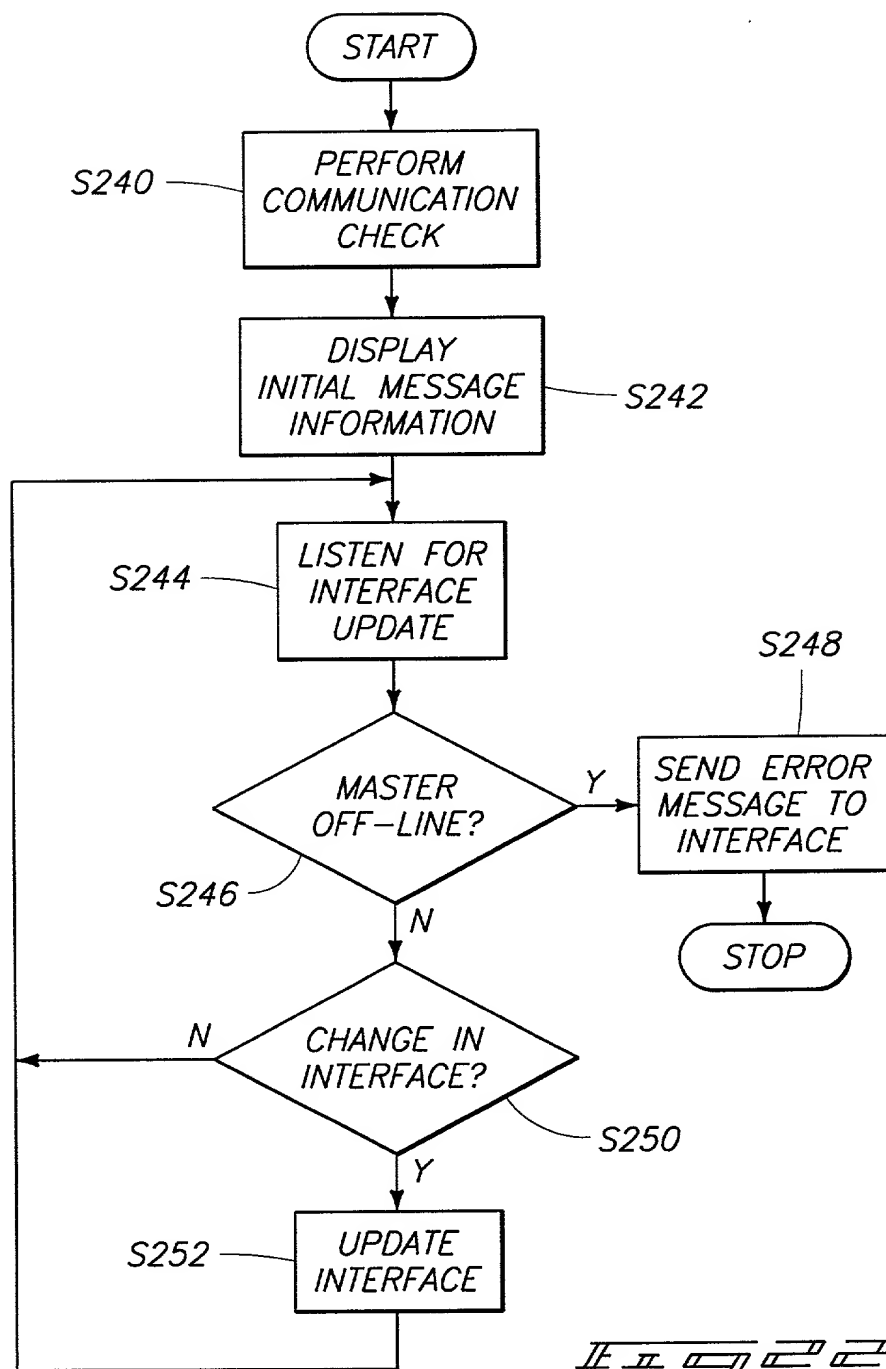


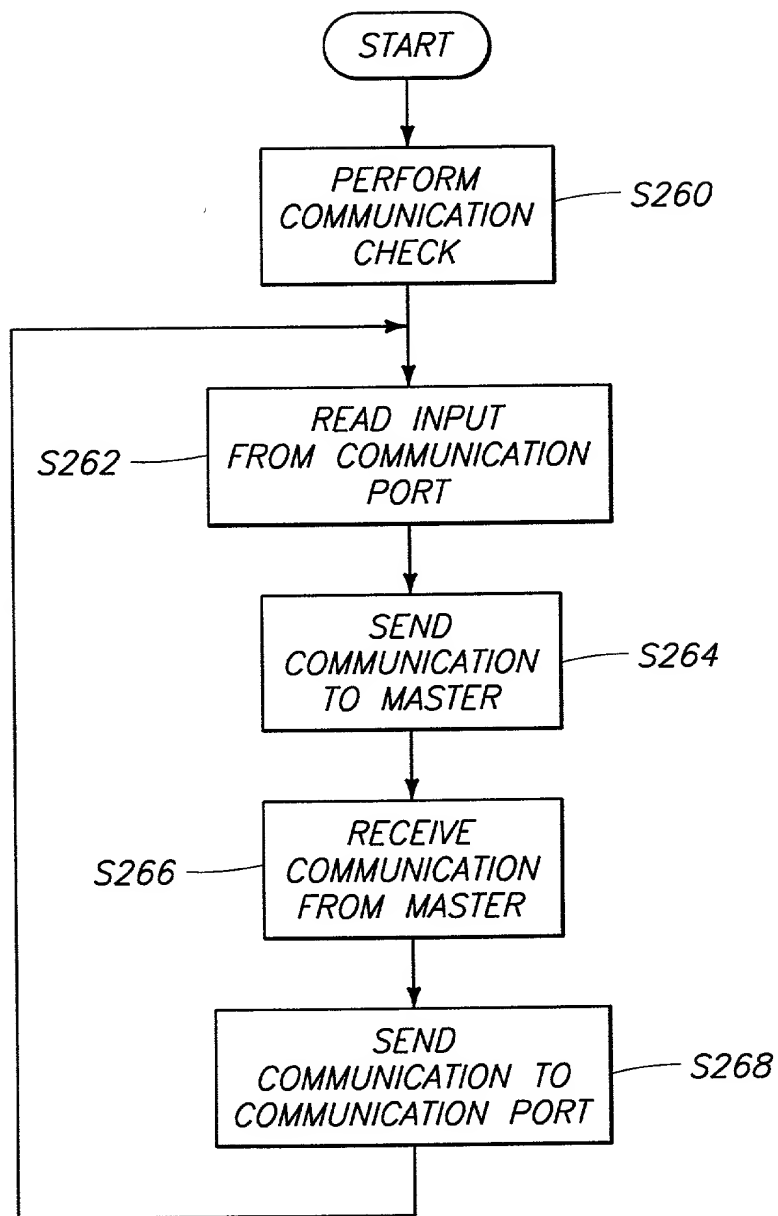
FIG. 21A

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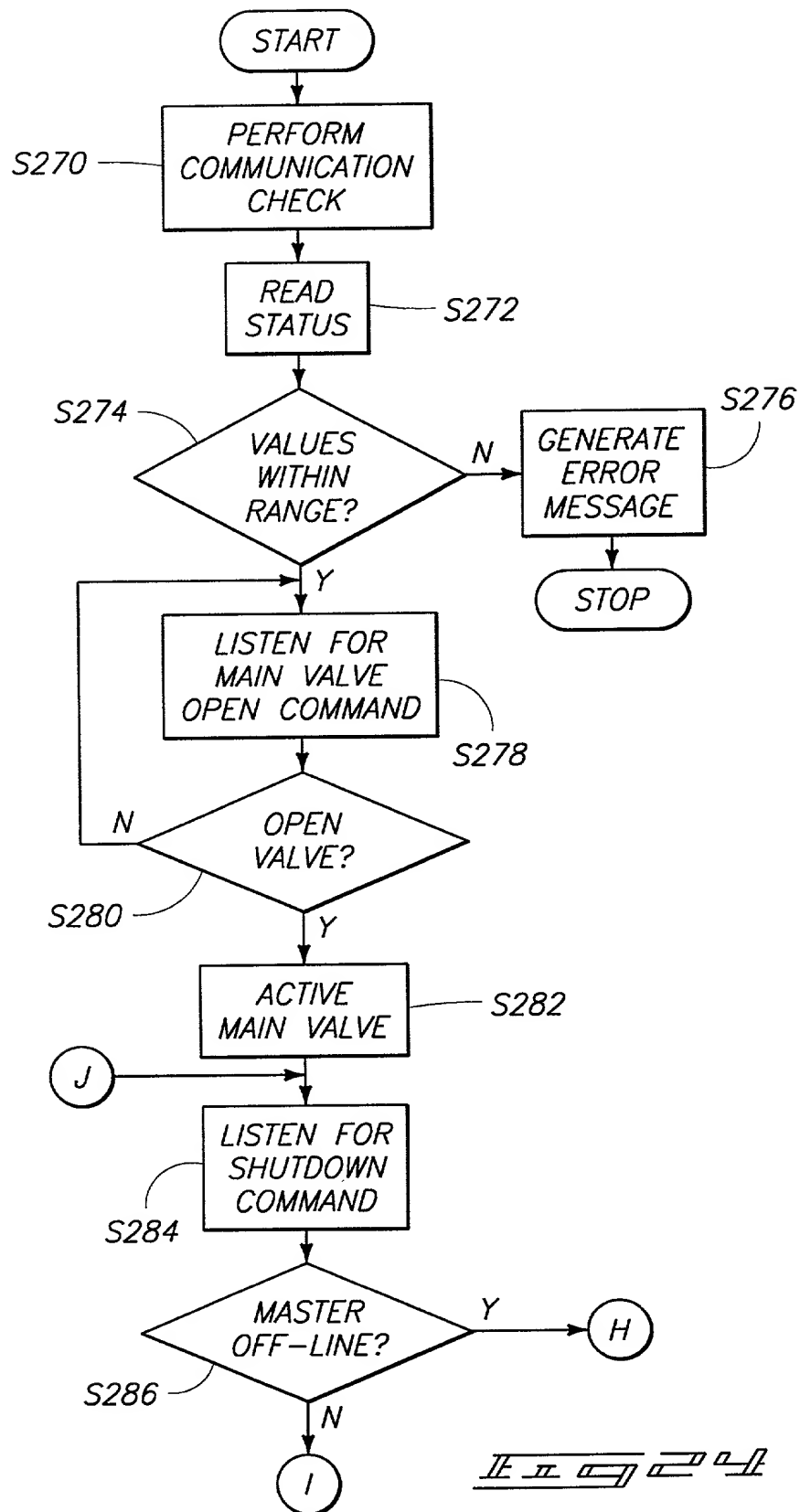
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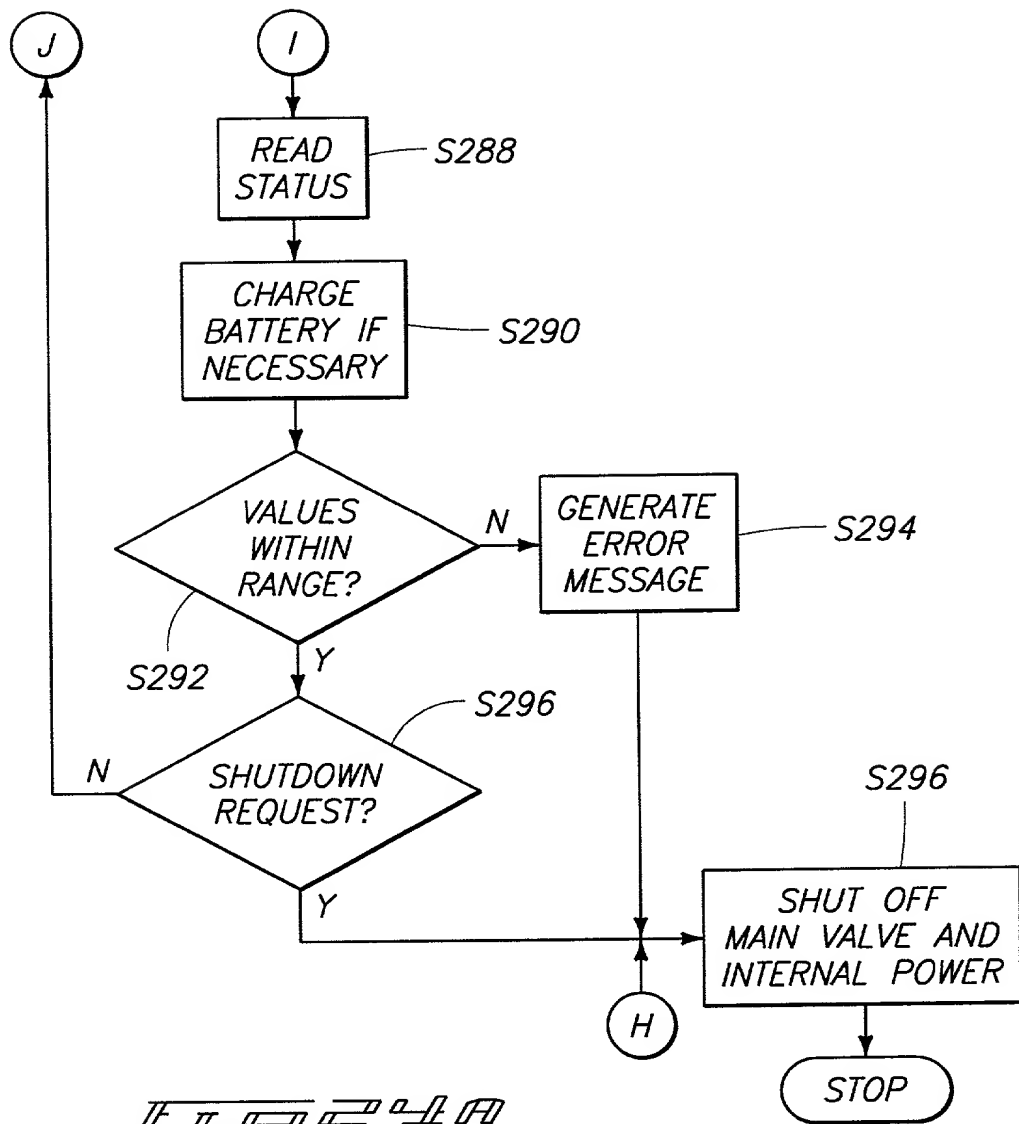
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FIG. 23

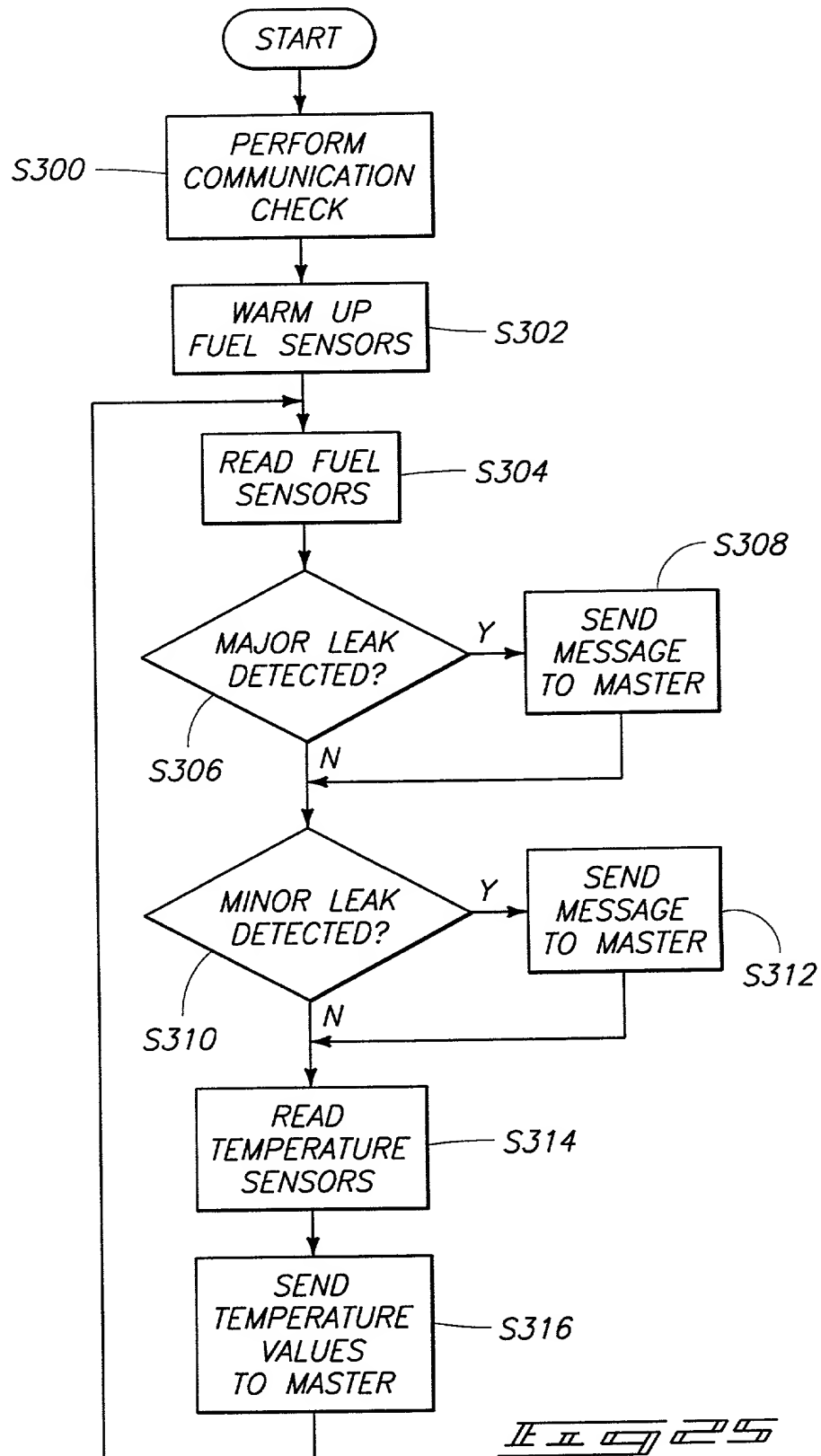
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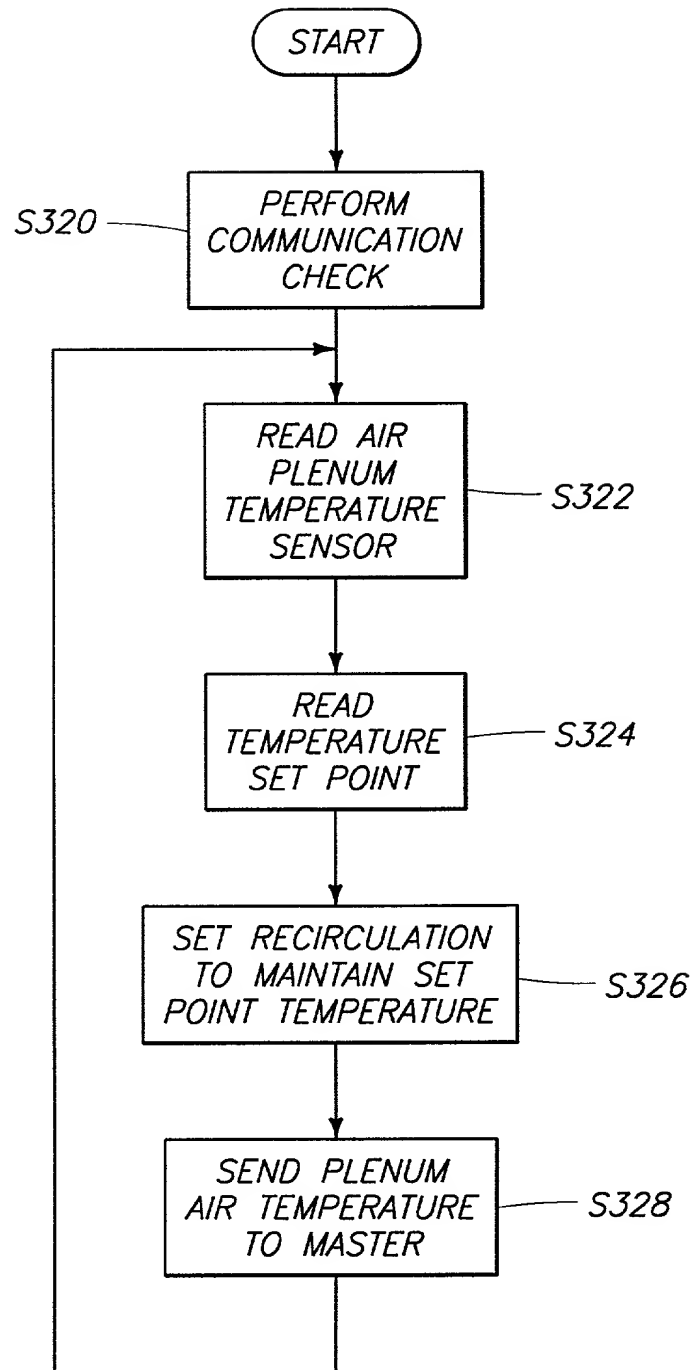
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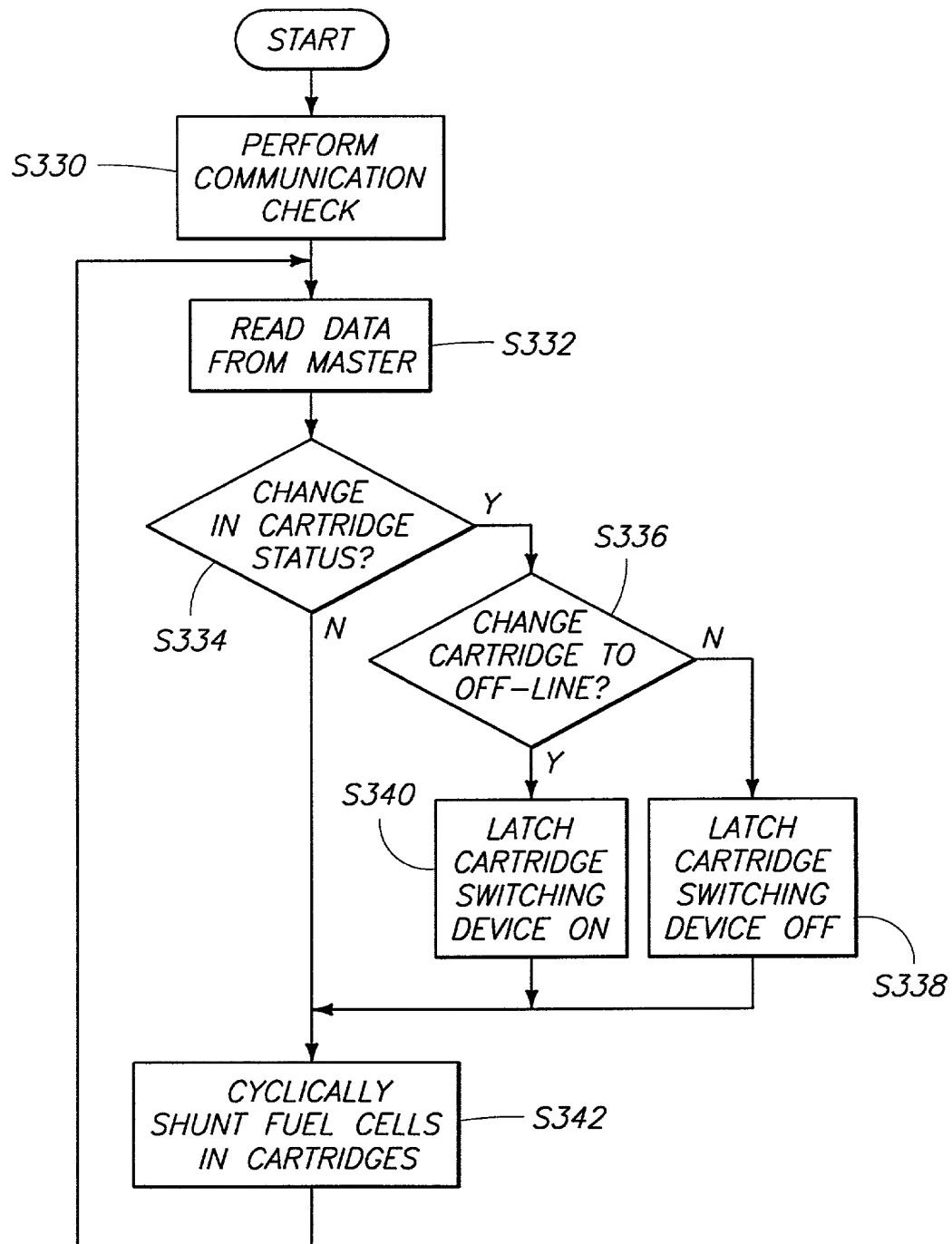
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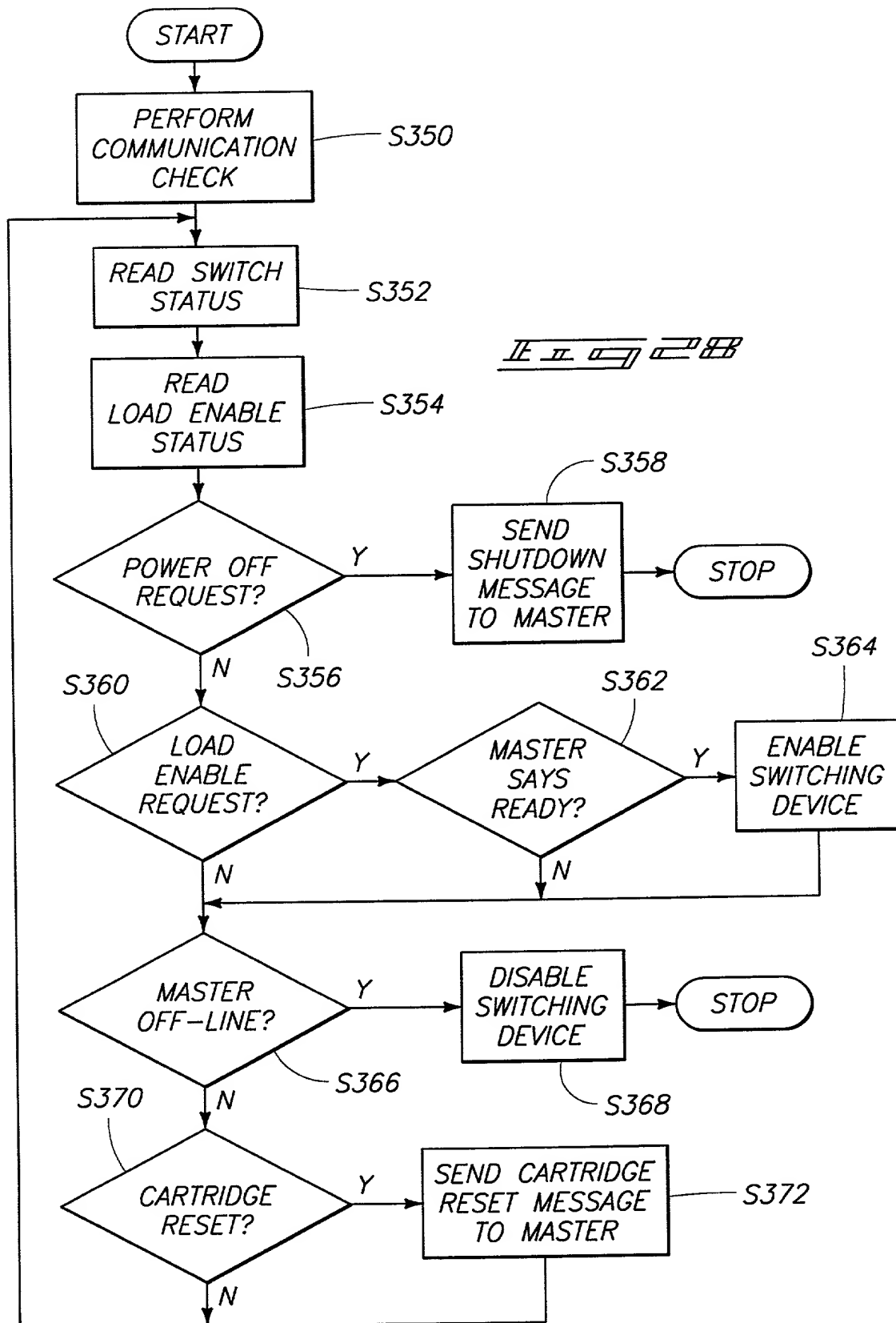
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Fig. 27

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DECLARATION OF JOINT INVENTORS FOR PATENT APPLICATION

As the below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled: **Fuel Cell Power Systems and Methods of Controlling a Fuel Cell Power System**, the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims.

I acknowledge the duty to disclose information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations §1.56.

PRIOR FOREIGN APPLICATIONS:

I hereby state that no applications for foreign patents or inventor's certificates have been filed prior to the date of execution of this declaration.

POWER OF ATTORNEY:

As a named Inventor, I hereby appoint the following attorneys and agent to prosecute this application and transact all business in the Patent and Trademark Office connected therewith: Richard J. St. John, Reg. No. 19,363; David P. Roberts, Reg. No. 23,032; Randy A. Gregory, Reg. No. 30,386; Mark S. Matkin, Reg. No. 32,268; James L. Price, Reg. No. 27,376; Deepak Malhotra, Reg. No. 33,560; Mark W. Hendricksen,

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1 Reg. No. 32,356; David G. Latwesen, Reg. No. 38,533; George G.
2 Grigel, Reg. No. 31,166; Keith D. Grzelak, Reg. No. 37,144; James D.
3 Shaurette, Reg. No. 39,833; Frederick M. Fliegel, Reg. No. 36,138; and
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9 I hereby declare that all statements made herein of my own
10 knowledge are true and that all statements made on information and
11 belief are believed to be true; and further that these statements were
12 made with the knowledge that willful false statements and the like so
13 made are punishable by fine or imprisonment, or both, under
14 Section 1001 of Title 18 of the United States Code and that such willful
15 false statement may jeopardize the validity of the application or any
16 patent issued therefrom.

17 * * * * *

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